NISTIR 6419

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E.0.1 NIST Cavity Fission Source (CFS) -
Operations Manual

**J.A. Grundl**

U.S. DEPARTMENT OF COMMERCE
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April 2000

U.S. DEPARTMENT OF COMMERCE
William M. Daley, Secretary

TECHNOLOGY ADMINISTRATION
Dr. Cheryl L. Shavers, Under Secretary
of Commerce for Technology

NATIONAL INSTITUTE OF STANDARDS
AND TECHNOLOGY
Raymond G. Kammer, Director

# ABSTRACT

Standard neutron fields have been developed at NIST beginning as early as 1975. They have been applied since that time as irradiation facilities and benchmarks for (1) validation of microscopic neutron interaction data for the design and operation of nuclear reactors of all types; (2) characterization of in situ neutron fields for reactor materials dosimetry; and (3) neutron transport calculations. This series of NIST Interagencey Reports (NISTIR) provides a detailed description of three of these neutron fields: the Cavity Fission Source (CFS), The Californium-252 Fission Neutron Irradiation Facility (CNIF), and the Materials Dosimetry Reference Facility (MDRF). This report provides operational information for the CFS including facility configuration, assembly and irradiation procedures, and neutron fluence determination.

NOTE:

- o This document describes facility operations and irradiation procedures as of 1995.
- o Dimensions and related specifications of facility hardware and reactor components are in the engineering units employed in the primary documentation upon which this report is based.

# A. INTRODUCTION

A.1 Facility Configuration

A.2 Summary Information and Notes

A.3 Logs and Test Report
--irradiations
--central penetration setup
--capsule and detector locations
--typical test report

## A.1 FACILITY CONFIGURATION

Configuration

[References: Sect.E.2.2, Mc82a, Mc84a, La82a]

The NIST cavity fission source operates at the center of a 30 cm diameter spherical cavity in the graphite thermal column of the NIST Research Reactor. The fission source consists of two coaxial source disks of 93.5% enriched $^{235}U$ metal (16 mm dia × 0.13 mm thick) mounted on source tabs attached to a source insertion tube. (Upper case letters in parenthesis are either abbreviations or component identification for pieces and assemblies -- see Section C.4)

Fig.B1-1 Cross section of the central penetration at the thermal column with cavity at the center. Shield boxes on the left provide access for inserting the source insertion tube (SI). Fig.B1-1a provides more dimensional detail.

Fig.B1-2 shows the source tabs in place at the center of the graphite cavity assembly block. (Top half of the cavity block is removed.)

The detector capsule, mounted in an insertion assembly (CI), slides into the source insertion tube. When in place the detector capsule may be extended to slide in between the source tabs.

Fig.B1-3 shows the detector capsule partially inserted into the source tabs.

Fig.B1-4 shows the detector capsule fully inserted into the source tabs. The source disk is visible under a tension attachment wire.

The detector capsule consists of a cylindrical cadmium box with the detectors mounted inside. They are located near the midplane with an inner detector holder and aluminum spacers.

Fig.B1-6 shows the detector capsule assembly pieces including the cadmium enclosure (left and right), the inner detector holder (center), and five detector foils with spacer rings. The spacer rings (0.010" thick) are intended to reduce effects of grazing angle scattering between detectors.

Fig. B1-5 is cross section of the detector capsule showiing the detector assembly region inside the cadmium capsule (cross hatched). Detectors are typically thin foils not more than 0.5" in diameter. The position of each detector relative to the midplane between the fission source disks, Z, is obtained from the distance S measured with a depth micrometer.

Details of assembly insertion procedure are in Section C.3. Photographs of hardware, assemblies, and thermal column access are in Section C.4.4.2.

For more information see Section B.1 of the Facility Characteristics Manual.

Abstract Of Irradiation Procedure

1. Follow general instructions regarding radiation safety (Section C.2)

2. Thermal column operations (Section C.1, Check List / Section C.2)

> Assemble foils into the cadmium detector (CC) capsule and record all dimension information

> Insert into the detector capsule holder (CIb) at the tip of the detector capsule insertion assembly (CI). Snap on cover. Withdraw holder.

> Insert CI into the source insertion tube (SI) and attach with screw. Insert push rod (CIb) and secure with clamp.

> Insert SI into thermal column with outer shield boxes (SB2, SB3) removed. Replace shield boxes.

> Raise and lower boral curtain to begin and end irradiation.

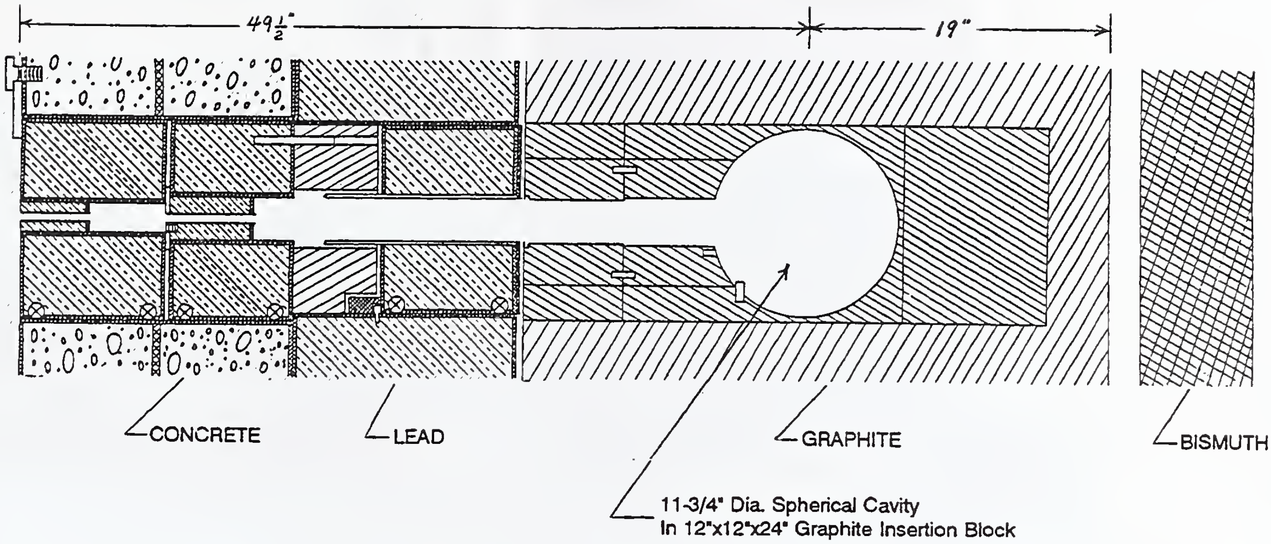



Fig. B1-1. Cavity access arrangement at the NIST reactor thermal column. The outer face of the thermal column door is at the left, and to the right (not shown) the heavy water and reactor core. Three removable shield boxes are shown with typical penetration reduction plugs in place. The CFS is inserted from the left with the middle and outer shield boxes removed. Neutrons from the reactor are admitted into the thermal column by means of a boral curtain that is raised in the space between the graphite and bismuth.

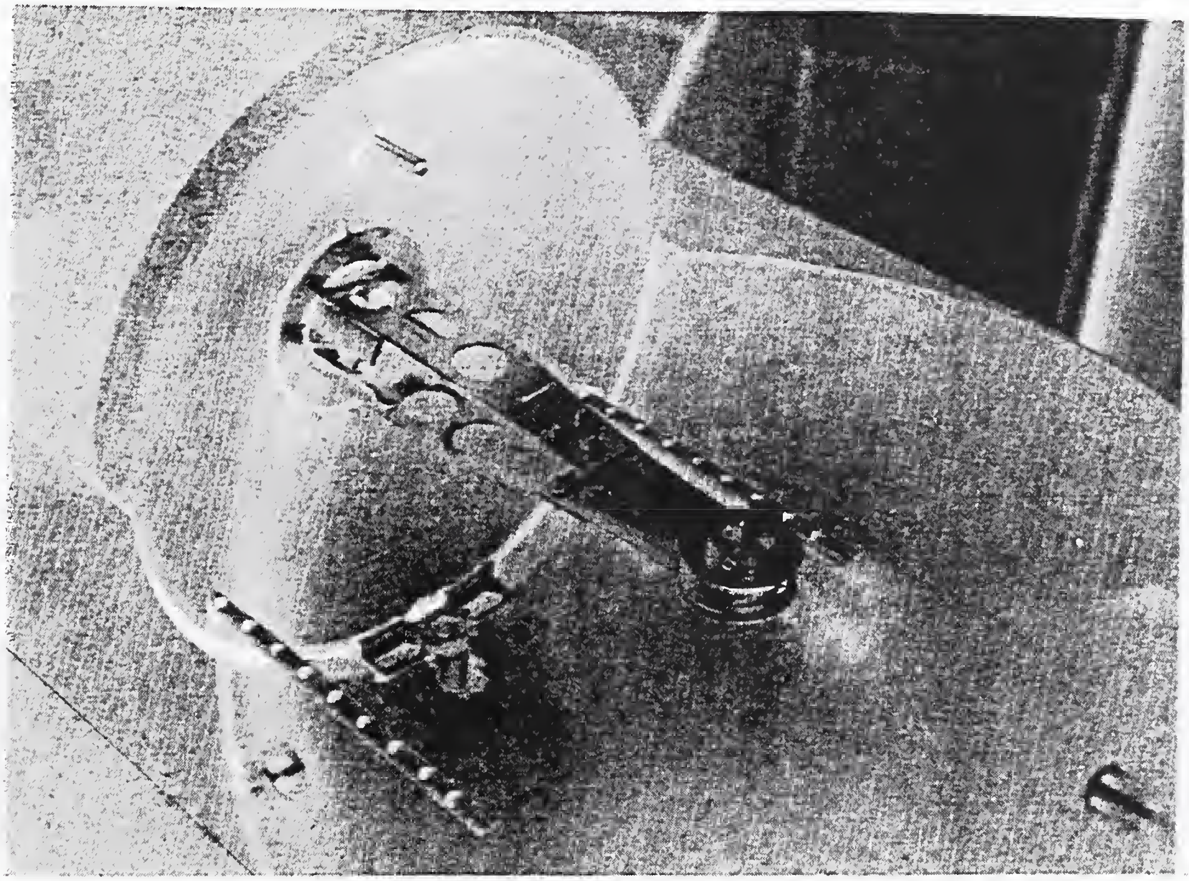
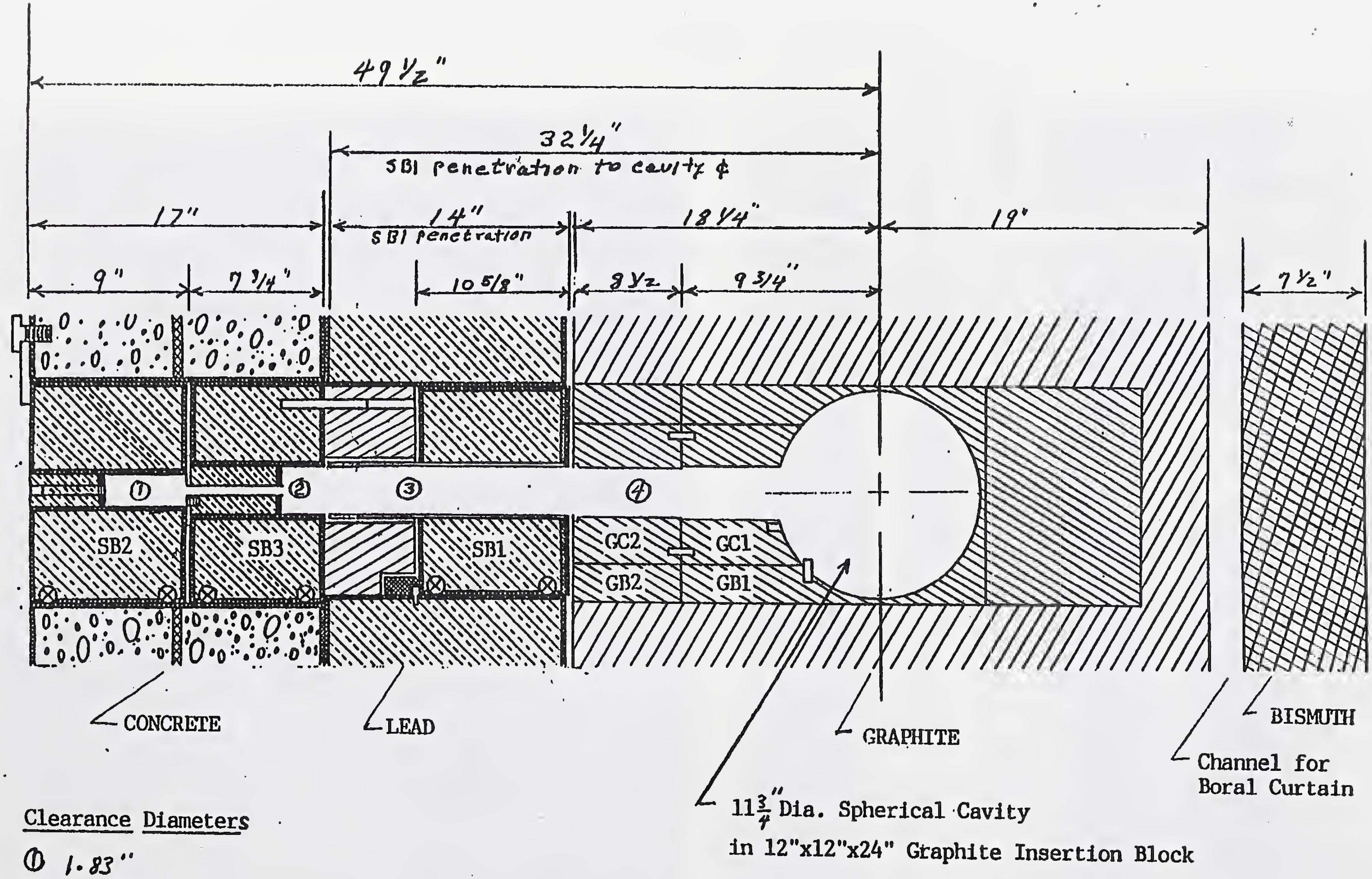


Fig. B1-2. Cavity Fission Source in place at the center of the spherical cavity. Photo taken with the graphite insertion block removed and with top section removed.




Clearance Diameters

① 1.83"

② 2.748"

③ 2.690"
1.870" w/reduction tube, SB1b
1.635" w/CFS guide tube, SB1d

④ 2.74"

4-16-90

Fig. B1-1a. CROSS SECTION OF CENTRAL PENETRATION WITH CAVITY ASSEMBLY

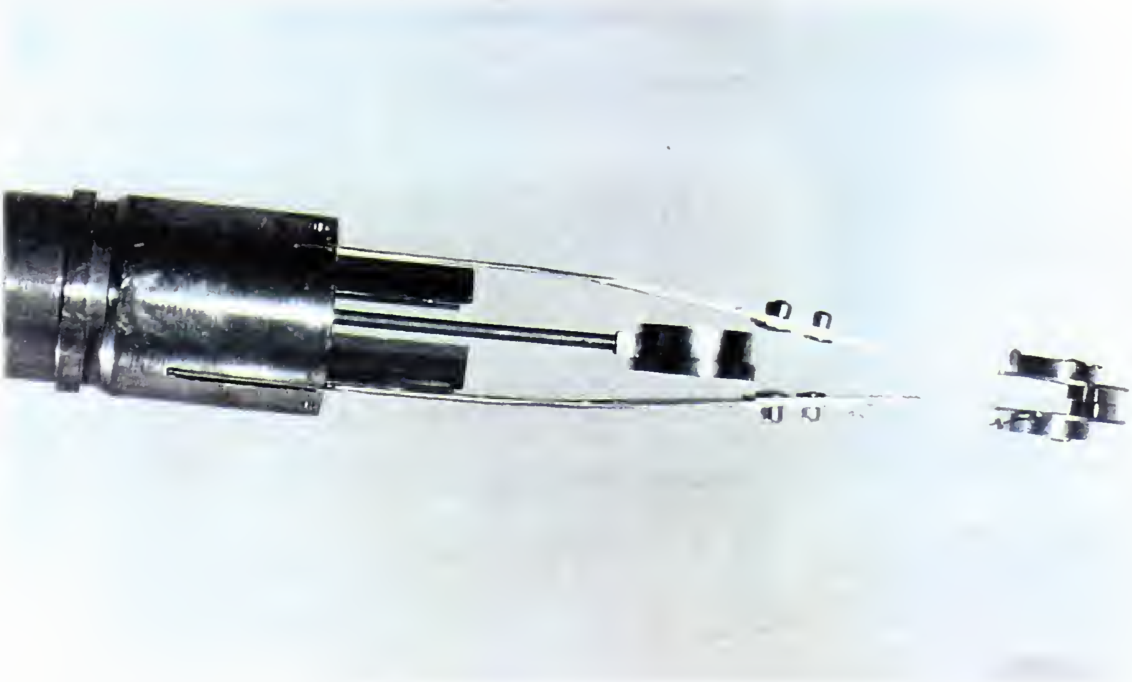


Fig. B1-3. CFS source tabs with detector capsule partially withdrawn.

Fig. B1-4. Close-up of the source tabs with detector capsule inserted. The wrapped fission source disk is under the coiled wire spring. [More recently, the fission disks are held in place with an aluminum twist lock.]

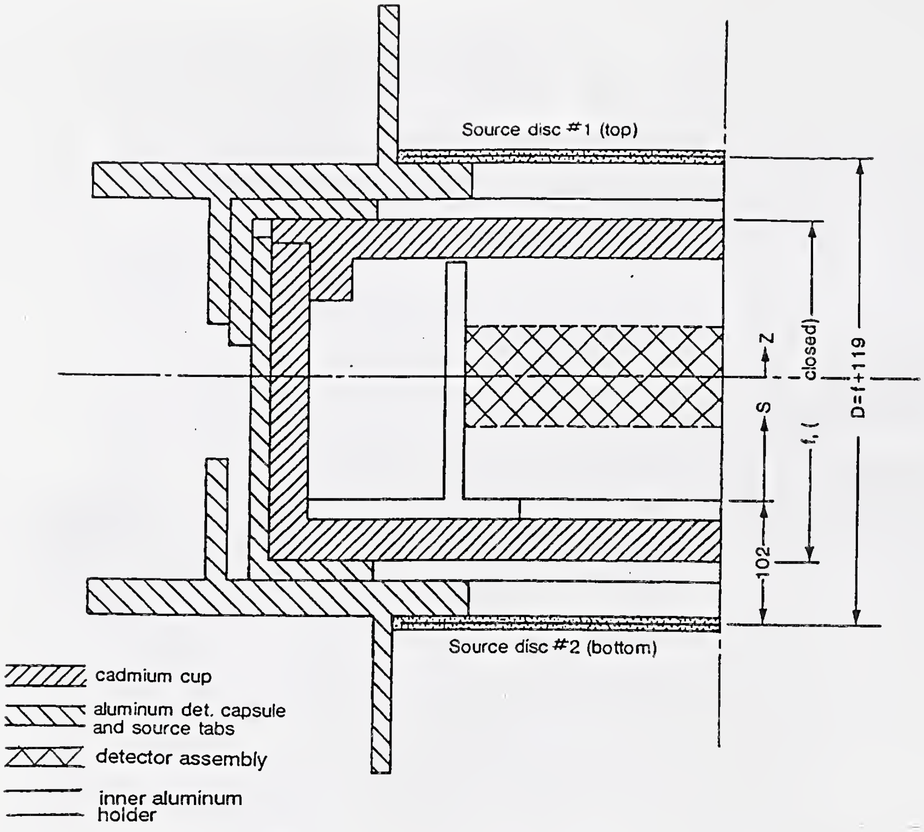



Fig. B1-5. Cross section sketch of the cavity fission source used in detector assembly procedure and for modeling Monte Carlo scattering calculations. Shown are the top and bottom fission source disks, source tabs and detector capsule holder, cadmium detector capsule, inner detector holder, and region of detector placement.

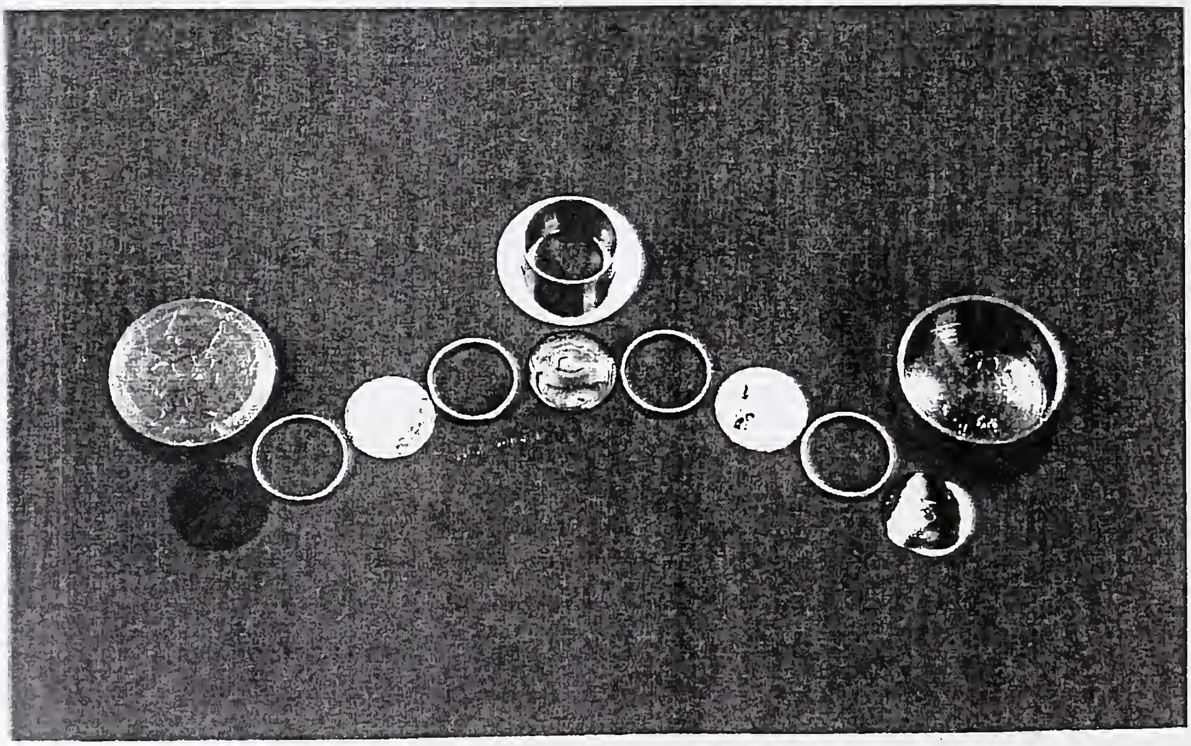


Fig. B1-6. Photo of detector assembly pieces: cadmium cover and cup (to the left and right), inner detector holder, and five detector foils with spacer rings.

Summary Information

>Neutron fluences of up to $5x10^{15}$ n/cm$^2$ can be delivered in about 35h to thin disk detectors on the midplane between the fission source disks. The routinely usable irradiation space is 1.3 cm in diameter (for nominal 0.5" diameter activation foils) and 1mm above and below the midplane.

>Fluence rates at the midplane are $\approx 4x10^{10}$ n/cm$^2$,s for the reactor at 20MW.
Nominal accuracy ($1\sigma$) for the fission neutron fluence rate is ±2.5%.

> Corrections for cavity return and capsule scattering for representative detector reactions:

| | U235 | Np237 | U238 | Ni58(n,p) | Al(n,$\alpha$) |
|---|---|---|---|---|---|
| threshold (MeV) | 4E-7 | 0.7 | 1.5 | 2.1 | 6.5 |
| cavity return | 12% | 0.36% | 0.21% | 0.1% | <0.1% |
| capsule scattering | +2.6% | +1.4% | +0.5% | 0.0% | -0.6% |

>Radial gradients of the neutron fluence at the detector are substantial:
center-to-edge ratios are $\approx 1.25$.

>Gamma-ray dose from the fission sources, the cadmium enclosure, and thermal neutron capture in graphite is approximately 10kGy/h.

>Related Documentation -- see Section E

CAVITY FISSION SOURCE IRRADIATION LOG
[protocol for irradiation designation after 1986:
U,month,date,year, sample: U011391 for irrad on Jan. 13, 1991]

| I.D. | EOI DATE | EXPOSURE | MATERIALS IRRADIATED |
|---|---|---|---|
| Diag. #1 | 1/20/83 | 0.54th | In (3)D |
| Ti/Ni-1 | 1/25/83 | 96.9h | In(3); Ti(2); Ni(2)D |
| Fe/Ni-1 | 2/6/83 | 72.3h | In(3); Fe(2); Ni(2)D |
| Ti/Fe-1 | 3/1/83 | 95h | In(3); Fe(2); Ti(3); Ni((1)D |
| Rh/Fe-1 | 4/6/83 | 2.0h | In(3),Rh(3), Al(2)D, Rh/Al-1 |
| Al/Fe/Ti-1 | 4/8/83 | 17h | In(3); Fe(2); Al(2); Ti(1)D |
| Ti/Fe-2 | 8/26/83 | 94.2h | In(3); Fe/Ni(1); Ti(3)D |
| U/Fe-1 | 11/14/83 | 94.6h | In(1); Fe/Ni(1); Ti(1) Ni(2); U-8(1) |
| U/Fe-2 | 11/20/83 | 97.8h | Ni(1); Fe/Ni(2); Ti(1); U-8(1); In(1) |
| VV-1 | 1/12/84 | 1.2h | Np; U8; In(3)D |
| VV-2 | 1/12/84 | 1/2h | Ni; Fe; Al; Mg; In(3)D |
| U/ORNL | | 2h | U8; Cu; InD |
| Ti/Fe-3 | 8/10/84 | 95h | Ti(2); Fe(2); Ni(2)D |
| U/Fe-3 | 8/30/84 | 149h | U8Nat(4); Fe/Ni(1); Ni(3); NbD |
| WIL785 | 7/19/85 | 96h | Ni(5); Nb(3);D |
| KAM985 | 12/4/85 | 74h | Fe/Ni(1); Fe(1); Ni(2); Ti(1)D |
| McL-1,2,3,4 | 9/85D | 0.5h | McLaughlin dosimeters |
| 8601 | 1/20/86 | 48h | Au(2); Ni(4); Sc(1)D |
| 8606 | 7/7/86 | 31d | Nb(3); Cu(2) Ni(3)D |

CAVITY FISSION SOURCE IRRADIATION LOG -- Continued

| I.D. | EOI DATE | EXPOSURE | MATERIALS IRRADIATED |
|---|---|---|---|
| U51286 | 12/14/86 | 91h | Nb(4); Ti(1); Np(1); Fe(2); Ni(4)D |
| U011391 | 01/13/91 | | Fe(2 );Ti(2 ) |
| U052491 | 05/24/91 | 71h | Ni(5), Fe(2), Cu, Ti |
| U091091 | 10/09/91 | 45h | Ni(4) |
| U061992 | 6/19/92 | 0.2h/15MW | S(1), Ni(2) |
| UNP62492 | 6/25/92 | 20h | Ni(2), Np wire |
| U100793 | 10/9/93 | 52h | Ni(3), Fe(2), Ti(1) |

Log of Central Penetration Setup

DATE GRAPHITE CAVITY ASSEMBLY INNER SHIELD BOX

[Reduction cylinder?
CFS guide tube?

==========================================================

Log of Capsule and Detector Locations

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Typical Test Report [following pages]

>Test Reports, irradiation records, and preliminary information sheet are kept in file cabinet in RmA158 [see also fac/cfstrpts]

>A typical Test Report without background information attachment is included in this section. The inventory of uncertainties is no longer applicable.
[see Section B.3.1 of CFS/Fac.Char. document]

>Test Report forms are in Section D.3 of this manual

TYPICAL TEST REPORT
(forms in Sect. D.3.)

NEUTRON FLUENCE CALIBRATION AT THE NIST $^{235}$U CAVITY FISSION NEUTRON SOURCE

Irradiation ID: U100793 Report Date: 22February94

Sensor Materials Irradiated: Ni, Fe, Ti

foil i.d. (this report): Ni-52, Fe-X11, Ti-17

End of Irradiation (EOI): 11:11:00 **EST** / 09October93

REPORT:

Free field, fission-neutron fluence (averaged over volume of the detector) with an assigned uncertainty of ±2.3% (±4.6% expanded):

$\Phi$ = 4.024E15 n/cm$^2$ for Ni-52

$\Phi$ = 4.103E15 n/cm$^2$ for Fe-X11

$\Phi$ = 4.005E15 n/cm$^2$ for Ti-17

Physical description:

Form: 12.7 mm dia. × 0.28mm(Ni), 0.51mm(Fe), and 0.56mm(Ti) thick disks

Material: Ni and Fe metal foils from Reactor Experiments

Additional parameters of irradiation:

Decay correction factor:

C = 0.991(Ni) using $\lambda$ = 1.1328E-07/sec

C = 0.998(Fe) using $\lambda$ = 2.571E-08/sec

C = 0.9924(Ti46) using $\lambda$ = 9.572E-08/sec

Length of irradiation: T = 1.598E05 sec

Departure from free-field activity due to neutron scattering
(uncertainty is 25% of the value given):

$\mu_{sc}$ = -0.0113(Ni) / -0.00834(Fe) / -0.01825(Ti)

Radial gradients of the neutron fluence are substantial: center-to-edge ratio is about 1.2 for 12 mm diameter sensor disks.

Other Radioactivities: Since the sensors are natural metal samples, activities from neutron reactions in other isotopes and impurities may be present. Ordinarily, this will not be a problem for Ge(Li) and other high resolution gamma detectors. The following lines have been observed above the annihilation energy:

Reference Documents:

(1) G. P. Lamaze and J. A. Grundl, "Activation Foil Irradiation with Californium Fission Source," NBS SP-250.13, U.S. Department of Commerce (March 1988).

(2) "Compendium of Benchmark Neutron Fields for Reactor Dosimetry," NIST Document NBSIR-3151 (January 1986).

Fluence standard prepared by:

________________________________________

E. D. McGarry / J. A. Grundl
Neutron Interactions and Dosimetry Group

Reviewed by:

____________________________

J. A. Grundl
Neutron Interactions and Dosimetry Group

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<u>File copy only</u>

Data on spreadsheet:

| laboratory | contact | Irr. Sensors sent | Test Report sent |
|---|---|---|---|
| Phoenix Lab, UMich | R. Venkataraman | Feb94 | 24Feb94 |

Inventory of Uncertainties For Calibration of the CFS Via the Pu239(n,f) Reaction ($\pm 1\sigma$)*
[Revised October, 1987]
[After 1990: items 3 & 4 replaced by a single value of ±1.5%; new total uncertainty is ±2.5% -- see CFS/Fac.Char. document, Section B.3.2]

o Neutron Fluence Transfer From the $^{252}$Cf Standard Fission Neutron Field to the $^{235}$U Cavity Fission Source:

| | |
|---|---|
| (1) Absolute neutron source strength of the $^{252}$Cf source | 1.1% S+R |
| (2) Distance measurement | 0.2% R |
| (3) $^{252}$Cf-to-$^{235}$U spectrum-averaged cross section ratio for Pu(n,f) transfer reaction | 0.1% S |
| (4) Neutron scattering correction for Pu(n,f) transfer reaction | 0.9% S |
| (5) Reproducibility of fluence transfer procedure (including counting statistics and electronic system stability over period of measurement) | 0.4% |
| (6) Neutron scattering correction in Ni fluence transfer monitor | 1.4% S |
| | ------------- |
| Quadrature sum: | 2.1% |

o Neutron Fluence Calibration at the $^{235}$U Cavity Fission Source

| | |
|---|---|
| (1) Gradient corrections and positioning | 0.4% S+R |
| (2) Neutron scattering corrections for $^{58}$Ni(n,p) | 0.8% S |
| (3) Reproducibility of fluence monitoring including random summing corrections and uncertainties in activation decay corrections | 0.3% R |
| | ----------- |
| Quadrature sum: | 0.9% |
| | ---------------- |
| Total Uncertainty: | ±2.3% (±4.6% expanded) |

---

*S is for systematic uncertainty and R is for random uncertainty.

# B. DETECTOR ASSEMBLY AND NEUTRON FLUENCE

## B.1. FOIL DETECTOR ASSEMBLY

### B.1.1 General Information

References

--i.d. of assembly hardware in Section C.4.1
--summary of photo locations and designations in Section C.3.0
--Detector Assembly Worksheet (Sect.D.1.1)
--complementary information in Sect.4 of SP250-14
[Ref.88-4 in Sect.E.1.1 (Hard Copy) in CFS-Fac.Char., Section E binder]

Assembly Visuals:

Fig.B1-6 in Section A.1
Figs.CC Section C.4.4.2
Sample worksheet in section D.1.1
Fig.B1-2 in this section

Assembly Hardware: (From Sections C.4.1.4 and C.4.1.5)

| | i.d. symbol | storage site |
|---|---|---|
| a. cadmium capsule and cover (3 scribed A, B, C; C is most used) | CC(A,B,C) | HS5 |
| b. inner hat for disk shaped detectors | Ca | HS4 |
| c. spacer rings | Cb | HS4 |
| d. detector stack disassembly mandril | Cc | |
| e. lucite detector capsule holder | Cd | HS1 |

Summary

Thin disk detector foils along with a minimum of three Ni fluence monitor foils are assembled into the "inner detector holder," commonly called the "hat," (Fig.B1-6) with 10 mil spacers placed between. This foil stack should measure less than 0.1 inch in order to stay within a region of manageable flux gradients. Larger spacers are placed top and bottom to bring the center of the foil stack to the midplane between the fission source disks. One Ni fluence monitor is placed at the midplane and two others near the extremities of the foil stack. Details are in Sect.B.1.2. The assembled hat is placed into one of three cadmium capsules (CC) scribed A, B, or C. The latter capsule is most commonly used.

The assembled cadmium capsule is put into the lucite holder (Cd) and taken out to the thermal column table. Assembly into the capsule holder (CIb, Fig.B1-3,4) is taken up in Section C.3.2.2.

B.1.2 Foil Assembly And Worksheet

Fig.B1-2 shows the "detector assembly" ("the hat") inside the "inner aluminum holder." The enclosure elements from inside out are the hat with foil stack including Ni fluence monitor foils (cross hatched), the cadmium capsule and cover (CC), the capsule holder and cap, the source tab w/ fission source disk. The important dimensions Z, D, f, and S, for foil detector assembly are as follows:

S = distance from bottom of detector assembly hat to center of the foil.
= 237 - "Depth Measurement" - 1/2 foil thickness

f = dimension of assembled cadmium capsule

D = source disk separation: f + 118

Z = position of detector center relative to the midplane between the sources
= S + 115 - D/2 = S - f/2 + 56
(Z is zero at midplane and positive for positions above midplane and negative below the midplane)

This is described in detail on the notations page for the Detector Assembly Worksheet along with the formulations required to assign a final position Z.

Fig.B1-1 from Ref.82-4 shows a parabolic fit to measurements of the axial gradient of fission neutron flux between the two source disks. The midplane (Z=0) is at S = 120mils.

The assembly procedure for the hat uses the Detector Assembly Worksheet from Sect.D.1.1.

Step 1, Preliminary foil assembly without end spacers:
Insert 10mil spacer and bottom foil into the hat and measure the distance from the top of the hat to the top of the foil with a depth micrometer and record the value in column 4 of worksheet. Continue assembly of foils with spacer and record as indicated. (Remember to place three Ni fluence monitors near the extremities and near the center of the foil assembly.) Obtain values of S and Z for the Ni foils as described in the notations for the worksheet and enter in columns 5 and 6. This step may be done cursorily since it's purpose is to estimate the position Z for the center Ni fluence monitor foil.

Step 2, Final foil assembly with end spacers:
Choose two end spacers (generally 40 to 60 mils) that will bring the center Ni foil to near Z = 0, and such that when assembled the top spacer rises 10 mils or so above the top of the hat. Perform depth measurements for each foil as in step 1 and record in column 4. The expected value, "piece sum" in column 3 is obtained by adding the last measured thickness of foil and spacer from col.2 to the previous sum. Enter this value in col.3. This should match the measured value in column 4 to 5 mils or better. Obtain the distance S from depth measurements as described in the worksheet notations and record in col.5:

S = 237 - [depth measurement, col.4] - [half-thickness of foil]

Derive the position, Z, in mils of the foil center relative to the midplane between the fission source disks and record in col.6:

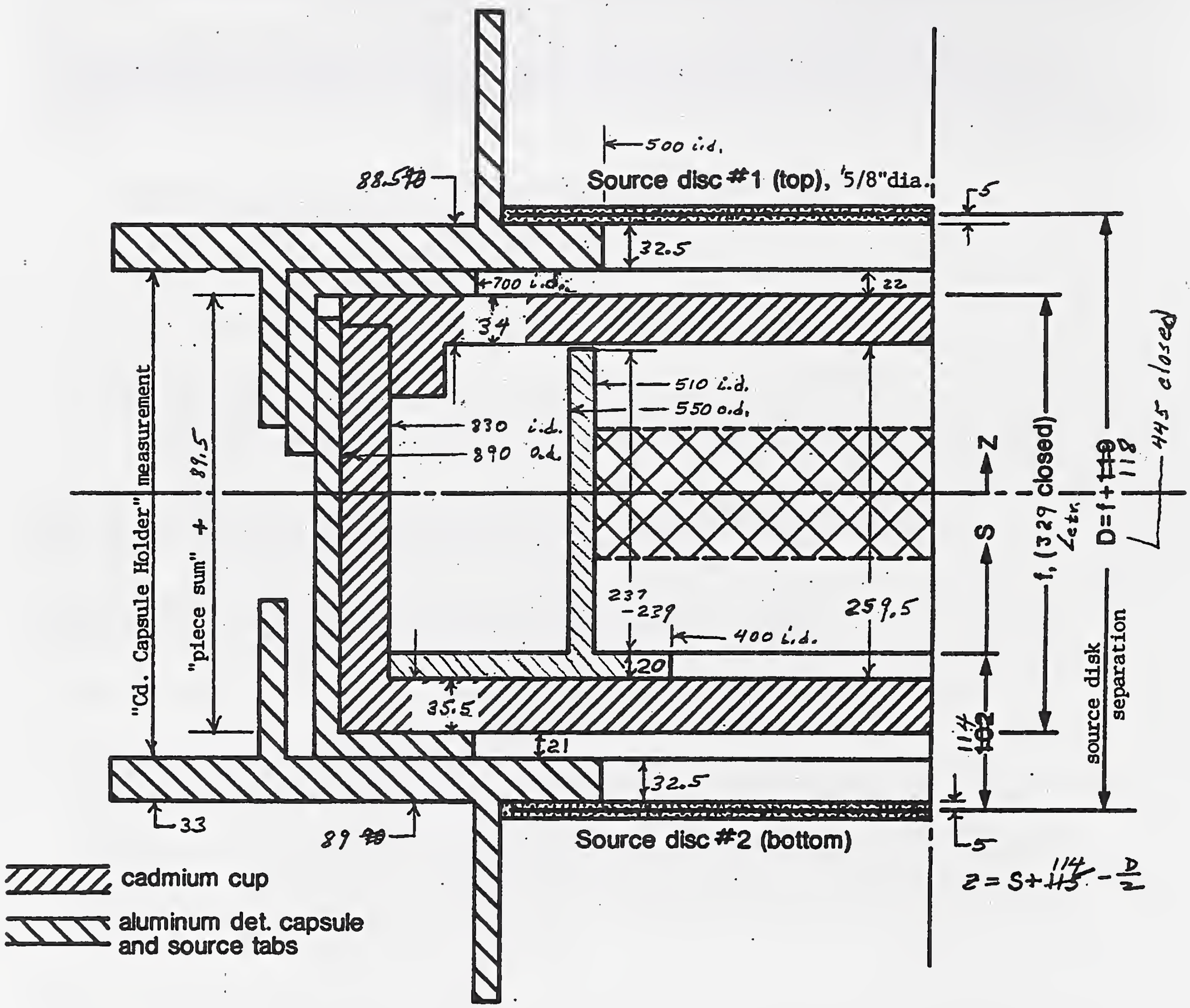
Z = S + 114 - D/2 = S - f/2 + 55.

This quantity is entered in Col.B of the FLUDER spread sheet (Col.B) -- see Section B.2

The assembled hat is placed into one of three cadmium capsule (CC) scribed A, B, or C. The most commonly used is capsule "C." The foil assembly should raise the capsule cover slightly to show that the foils are secure when the cover is closed down onto the capsule

The assembled cadmium capsule is then put into the lucite carrier (Cd, Fig.PA-CC-4) and taken out to the thermal column table. Assembly into the capsule holder (CIb, Fig.PA-CI-5) is taken up in Section C.3.2.2.

**Fig. B.1-2 HALF-SECTION DRAWING OF SOURCE DETECTOR ASSEMBLY**




Cadmium Capsule "C" (all dimensions in mils)

D = fission source disk separation distance (midplane is at D/2)

S = distance from bottom of detector assembly "hat" to the center of the foil.

Z = position of detector center relative to the midplane between the sources
(Z is zero at midplane and positive for positions above midplane,
i.e. towards upper source disk)
= S - 112 (nominal for capsule C)

[Measurement details are in notations for the Detector Assembly Worksheet.]

DETECTOR ASSEMBLY WORKSHEET FOR CAVITY FISSION SOURCE
[Worksheet form is in Sect. D.1.1 .

Assembly date: 10-7-93 Irradiation i.d. U100793 EOI: 10:11 EDT 09 Oct 93

| [1]Assembly Piece i.d. | thk. (mils) | Depth Measurement to Foil Surface (mils) piece sum | micro-meter | S assigned (mils) | Z see note (2) (D = 453) |
|---|---|---|---|---|---|
| | | bottom | 237 | | |
| Btm, Spacer | 40 | | | | |
| Nickel C | 10 | | 187 | 45 | -62 |
| Spacer | 11 | | | | |
| Fe-013 | 20.5 | 155.5 | 156.5 | 70 | -42 |
| Spacer | 10 | | | | |
| Nickel 52 | 11 | 134.5 | 139 | 93 | -19 |
| spacer | 10 | | | | |
| Ti-017 | 22 | 102.5 | 102 | 124 | +12 |
| Spacer | 6 | | | | |
| Fe-X11 | 20 | 76.5 | 79 | 148 | +36 |
| Spacer | 11 | | | | |
| Ni-14 | 10.5 | 55 | 60 | 172 | +60 |
| Top Spacer | 60 | — | — | | |

Assembled Cd. capsule ( C ): f = 335 ; capsule holder: 373

---

S = distance from foil center to bottom of detector assembly hat
Z = position of foil center measured from midplane between sources
[over]

NOTATIONS FOR DETECTOR ASSEMBLY WORKSHEET
[from Section D.1.1 / position parameters defined in Fig.B.1-2]

(1) Pieces are assembled with i.d. number up. All dimensions are in mils

(2) Error does not include uncertainty in midplane position. Position uncertainty for the monitor is relative to the adjacent foil.

------------------------------

S = distance from bottom of detector assembly hat to the center of the foil.

= 237 - ["Depth Measurement"] - [1/2 foil thickness] (nominal)

f = dimension of assembled cadmium capsule

D = source disk separation: f + 118

Z = position of detector center relative to the midplane between the sources
(Z=0 at midplane; Z is positive for positions above midplane, i.e., towards upper source disk)

= S + 114 - D/2 = S - f/2 + 56

--------------------------------

Example: Capsule closed (f=333 and D=451):

Z = S - 112

= 126 - ["Depth Measurement"] - [1/2 foil thickness]

-------------------------------

Assembled capsule holder: 370 (nominal)

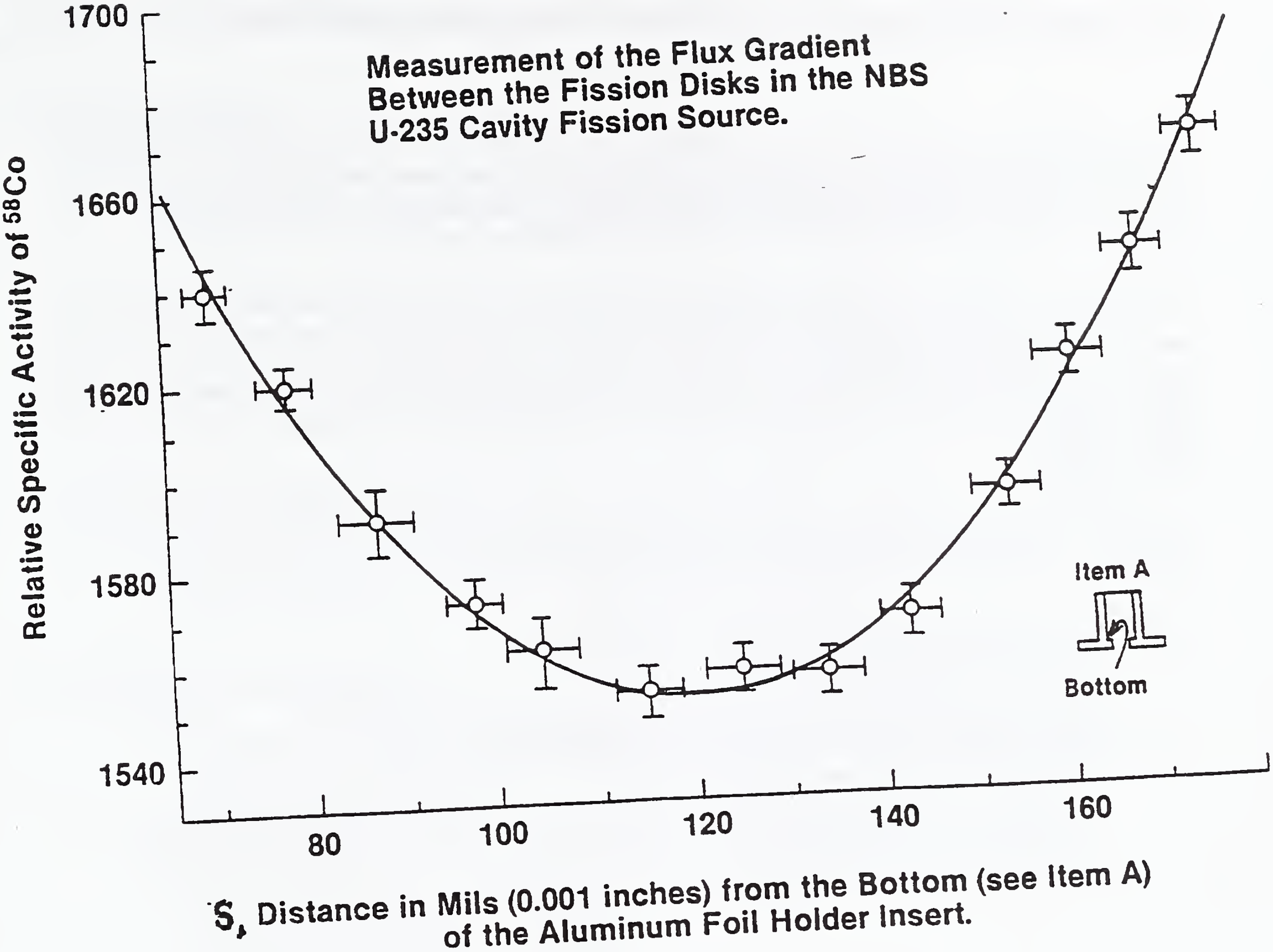



Fig.B1-1. Axial fluence gradient plot from Ref.82-4. The minimum fluence for the least-squares fit is at S = 120 mils, the midplane between the fission source disks.

The fluence relative to the midplane is given by,

$$\Phi = 1.347 - 5.81E\text{-}3\ S + 2.429E\text{-}5\ S^2 = 1 + 2.43E\text{-}5\ Z^2$$

The distances S and Z are shown in Fig.B1-2. Example: for S = 160mils (Z=40), $\Phi = 1.039$.

Note: The gradient parabola in the present version of FLUDER is based on more recent measurements (McGarry, Priv. Comm.) and differs somewhat from Ref.82-4:

$$\Phi = 1 + 2.12E\text{-}05\ Z^2$$

The QPRO spread sheet FLUDER establishes neutron fluence and fluence rate for detectors irradiated in the Cavity Fission Source based on the counter response of Ni58(n,p) activation monitors assembled with the detectors to be irradiated. The Ni monitor response is calibrated on the basis of neutron fluence transfer from the Cf252 Neutron Irradiation Facility, CNIF.*

The fission neutron fluence at each Ni monitor position in a cavity fission source irradiation is product of the k-factor from neutron fluence transfer and the Ni detector response. The neutron fluence at the CFS midplane is then derived from the average of the Ni monitor responses corrected to the midplane by means of an experimentally determined axial gradient. The neutron fluence for other irradiated detectors is assigned relative to the midplane value based on the same parabolic axial gradient.

Formulations for the spread sheet are in Section B.3.1 of the CFS Facilities Characteristics document. A summary is given here at the end of Sect. B.2.1.

The FLUDER spread sheet includes the following:

--the Ni monitor calibration factor, i.e. the "k-factor"
--corrections for activation decay
--neutron scattering in the source detector capsule and cavity return
--axial gradient of the fluence in the detector capsule
--residual counter response corrections related to foil thickness:
gamma absorption and shelf geometry
--neutron fluence and fluence rate at CFS midplane and for each detector position
--average reaction rate at each detector based on spectrum average cross sections

* The latter is embodied in a k-factor defined later in this section. The k-factor depends upon Ni activation counting efficiency and related counting procedures. It must be periodically checked and if necessary revised based on an absolute neutron fluence irradiation at the CNIF facility.

B.2.1 OUTLINE OF QPRO FORMAT

General Information

>Sample FLUDER spread sheet with annotation is in Sect. B.2.2 and Sect. D.2.1
--file locations: QPRO: C:\QPRO\FLUDER\FLDRM97.WQ1
WP5.1: C:\CFSCODES\FLUDER\FLDRM97.WQ1

>Working spread sheet file for new irradiations (Section D.2.)
--file locations: QPRO file: C:\QPRO\FLUDER\FLDRWRK.WQ1
WP5.1 file: C:\CFSCODES\FLUDER\FLDRWRK.WQ1
--retitle, delete, and overwrite appropriate input quantities
[do not close up blank rows]

>Uncertainty estimates are in Sect.B.3.1 of the CFS Facility Characteristics document.

>Background information is in folders marked "CFS: Operations Manual" and "CFS: Calculations." [set up in QPRO by E. D. McGarry]

Input Quantities for FLUDER

>From Detector Assembly Worksheet: foil i.d. (including Ni fluence monitors), position(Z), and thickness(T)
--columns A, B, C, A', B', A"

>From counting lab:
--Ni monitor response (c/s at EOI) (Col. E)
--counting shelf correction (Col. I)
--Ni fluence calibration factor (Col.K)
--the 1996 counting lab operations code is designated STP2D8

>From SCATCORR: code for neutron scattering corrections (Col. L)
--operations notes, annotation, and sample output are in Section D.2.3
--includes cavity return

>From SATFAC: activation decay correction (Col. U)
--use [1 - exp($-\lambda$T)] for uninterrupted irradiation at constant power level
--the SATFAC spread sheet in QPRO may be used for more complicated irradiation time history--see Section D.2.2.

Output Quantities for FLUDER

| | midplane | detector |
|---|---|---|
| >free-field neutron fluence | col. W | col. N |
| >free-field fluence rate | col. O | col. X |
| >average reaction rate ($\sigma\phi$) | col. Z | |

B.2.1 [continued]

FLUDER Spread Sheet Sections
(With selected spread sheet quantities; complete annotation in Sect. B.2.2

>Ni monitor response: Columns A thru M
[Underlined labels indicate input information.]

--col.B: Ni monitor foil position in mils (0.001") measured from the midplane between the fission source disks. In the Detector Assembly Worksheet, it is the quantity Z --see Sect.B.1

--col.D: the gamma absorption factor is a fixed parameter for deriving the gamma loss correction in col.H
--col.E: the Ni monitor response is furnished by the counting lab as c/s at EOI corrected for pulse losses and background from the PHD interpolation code
--col.L: neutron scattering correction from SCATCORR code which includes scattering in the capsule (Fig.B1-2), the foil stack, and cavity return -- see Sect.D.2.3 and CFS:Facility Characteristics, Sect.B.2

--col.H: gamma absorption factor
--col.I: shelf correction for foil thickness
--col.J: Ni monitor response in c/s per gm at EOI corrected for gamma absorption and shelf geometry
--col.K: parabolic gradient correction to midplane between fission source disks (Z=0) [updated gradient coefficient as noted in Fig.B1-1]
--col.M: free-field monitor response (c/s per gm) at midplane (Z=0) for each monitor with the average value and standard deviation right below

------------------------------

>Free-Field Neutron Fluence at Midplane, Z=0: Columns P thru X
(col.W) = (col.P) ["Average=" in col.M] / (col.V)

--col.P: "k-fact" is a composite factor for a specific counting geometry. It is based on neutron fluence transfer from CNIF, the Cf fission neutron irradiation facility. See CFS Facility Characteristics document, Sect.B.3.1, Eq.B-2.
--col.U: activation decay correction -- see Section D.2.2

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>Free-Field Neutron Fluence at Detector Position, Z(mils)
fluence: (col.N) = (col.W) (col.K')
fluence rate: (col.O) = (col.N) / (col.S)

--col.K': axial gradient at Z relative to midplane, Z=0

B.2.1 [continued]

Formulation and definition of the k-factor
[From CFS: Fac. Char. Doc., Sect. B.3.1]

With subscripts "cfs" for the Cavity Fission Source and "cnif" for CNIF, the expression which governs neutron fluence transfer from CNIF to CFS is,

$$\Phi_{cfs} = \left[\frac{\mu D}{GM}\right]_{cfs} \cdot \left[\frac{\sigma_{Cf}(>E_{95})}{\sigma_{U5}(>E_{95})} \cdot \frac{\psi_{Cf}(>E_{95})}{\psi_{U5}(>E_{95})}\right] \cdot \left[\frac{\mu D}{GM}\right]^{-1}_{cnif} \cdot \Phi_{cnif}$$

where

$\Phi_{cfs}$ = free-field fission neutron fluence
D = Ni detector response in a specific, reproducible counting geometry: net c/s at EOI corrected for backgrounds, gamma aborption, pulse losses and gains
[$D_{cfs}$ only: gamma absorption and shelf geometry are entered separately in FLUDER]
G = activation decay correction factor
M = mass of Ni58 detector (gm)
$\mu$ = response factors not included in D [gradients and neutron scattering mostly]

$\sigma(>E_{95})$ = truncated cross section for the Ni58(n,p) threshold reaction
$\psi(>E_{95})$ = spectrum fraction above $E_{95}$
$E_{95}$ = truncation energy
$\sigma(>0.4ev)$ = full spectrum-averaged cross section, i.e. E>0.4ev the cadmium cutoff
= $[\sigma(>E_{95})\cdot\psi(>E_{95})]$ / (0.95)

The last three factors on the right are the "K-factor" in FLUDER (col. P) obtained via neutron fluence transfer from CNIF.

Contemporary values for the ratios in the middle bracket of Eq.B-2 using fission spectrum shapes ($\chi$Cf:NBS) and ($\chi$U235:ENDF/BV) are,

| | | |
|---|---|---|
| truncated cross section [$\sigma(>E_{95})$] | 1.074 | [0.2845b/0.2650b] |
| spectrum fraction [$\psi(>E_{95})$] | 1.010 | [0.380 /0.3764] |
| full-spectrum cross section | 1.084 | [0.1138 /0.1050] |

Correspondence with the FLUDER spread sheet is as follows,

$\Phi_{cfs}$(midplane): col.W    $\Phi_{cfs}$(foil position): col.N

D: col.E    G: col.V    M: col.F    $\mu$: columns H, I, K, L,

$\mu$D(corrected to free-field at midplane): col.M

## B.2.2 ANNOTATED QPRO OUTPUT

SAMPLE FLUDER SPREAD SHEET FOR CFS OPERATIONS MANUAL, SECTION D.2.1
[PC file: C:\qpro\fldrm97.wq1 and C:\cfscodes\fldrm97.wq1

CAVITY FISSION SOURCE IRRADIATION 12-Mar-97
[irradiation i.d. / qpro file]

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I.D. | POS. | T(mils) | Mu(abs) | RATE(c/s) | MASS(g) | Rate/M | 1-e^-Mu*T | C(del r) | CORR. RT. | GRADIENT | MU SCAT | D CORRED |
| Ni-BT | -58.0 | 10.0 | 0.0015 | 1162.0 | 0.2810 | 4135.2 | 0.9925 | 1.0000 | 4166.3 | 1.071 | -0.0097 | 3927 |
| Ni-M | -29.0 | 10.0 | 0.0015 | 1115.0 | 0.2828 | 3942.6 | 0.9925 | 1.0000 | 3972.2 | 1.018 | -0.0095 | 3940 |
| Ni-U | 11.5 | 3.5 | 0.0015 | 308.9 | 0.0793 | 3894.7 | 0.9974 | 0.9974 | 3894.8 | 1.003 | -0.0111 | 3927 |
| Ni-N | 50.0 | 10.0 | 0.0015 | 1142.5 | 0.2824 | 4045.7 | 0.9925 | 1.0000 | 4076.1 | 1.053 | -0.0091 | 3906 |
| Ni-AK | 85.5 | 10.0 | 0.0015 | 1249.0 | 0.2814 | 4438.5 | 0.9925 | 1.0000 | 4471.9 | 1.155 | -0.0106 | 3913 |
| | | | | | | | | | | | AVERAGE= | 3923 |
| | | | | | | | | | | | STD.DEV.= | 12 |
| | | | | | | | | | | | %STD.DEV.= | 0.2998 |

| A' | B' | K' | N | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DETECTOR FREE-FIELD FLUENCE | FLUENCE RATE | | | | | | | |
| I.D. | POS. | GRADIENT | | | K fact | DUMMY | T 1/2(d) | t(sec) | LAMB.(1/s) | SATFAC | G |
| Ni-BT | -58.0 | 1.0713 | 7.227E+15 | 2.82E+10 | 1.920E+05 | 1.0000 | 70.82 | 256200 | 1.1328E-07 | 0.02861 | 1.117E-07 |
| Fe-H | -48.0 | 1.0488 | 7.075E+15 | 2.76E+10 | | | | | | | |
| Ni-M | -29.0 | 1.0178 | 6.866E+15 | 2.68E+10 | | | | | | | |
| Ti-BJ | -9.0 | 1.0017 | 6.757E+15 | 2.64E+10 | | | | | | | |
| Ni-U | 11.5 | 1.0028 | 6.765E+15 | 2.64E+10 | | | | | | | |
| Cu-AU | 30.5 | 1.0197 | 6.879E+15 | 2.68E+10 | | | | | | | |
| Ni-N | 50.0 | 1.0530 | 7.103E+15 | 2.77E+10 | | | | | | | |
| Fe-S | 68.0 | 1.0980 | 7.407E+15 | 2.89E+10 | | | | | | | |
| Ni-AK | 85.5 | 1.1550 | 7.791E+15 | 3.04E+10 | | | | | | | |

| W | X |
|---|---|
| FREE FIELD MIDPLANE FLUENCE | FREE FIELD MIDPLANE FLUENCE RATE |
| 6.746E+15 | 2.633E+10 |

| A'' | O' | Y | Z |
|---|---|---|---|
| I.D. | FLUENCE RATE | SIGMA (mb) | PHI*SIGMA |
| Ni-BT | 2.82E+10 | 105.00 | 2.963E-15 |
| Fe-H | 2.76E+10 | 81.00 | 2.238E-15 |
| Ni-M | 2.68E+10 | 105.00 | 2.815E-15 |
| Ti-BJ | 2.64E+10 | 11.20 | 2.955E-16 |
| Ni-U | 2.64E+10 | 105.00 | 2.773E-15 |
| Cu-AU | 2.69E+10 | 0.55 | 1.477E-17 |
| Ni-N | 2.77E+10 | 105.00 | 2.912E-15 |
| Fe-S | 2.89E+10 | 81.00 | 2.343E-15 |
| Ni-AK | 3.04E+10 | 105.00 | 3.194E-15 |

ANNOTATION OF THE QPRO SPREAD SHEET FLUDER -- 05March97
[from Section D.2.1]
[Underlined labels indicate input information. * From Detector Assembly Worksheet]

| Col. | Label | Explanation |
|---|---|---|
| **Ni Monitor Response** | | |
| A. | I.D. | *Ni foil monitor identification |
| B. | POS. | *Ni foil position measured from midplane<br>(Z in mils from Detector Assembly Worksheet) |
| C. | T(mils) | *thickness of Ni monitor foils in mils |
| D. | MU(abs) | $\gamma$ absorption factor |
| E. | RATE(c/s) | Ni monitor count rate from ctg lab (c/s at EOI)<br>(corrected for pulse losses and backgrounds) |
| F. | MASS(g) | Ni monitor foil mass (gm) |
| G. | Rate/M | Ni monitor response in c/s per gm<br>(col.E) / (col.F) |
| H. | (1-e^-Mu*T) | $\gamma$ absorption correction<br>[1 - exp(-(col.C)(col.D))] / [(col.C)(col.D)] |
| I. | C(del r) | shelf correction for foil thickness<br>1 + (0.008)[(col.C) - 10)]/2 |
| J. | CORR.RT. | corrected monitor response (c/s per gm)<br>(col.G)(col.I) / (col.H) |
| K | GRADIENT | neutron fluence relative to midplane<br>1 + (2.12E-5)(col.B)$^2$ |
| L. | MU SCAT | neutron scattering correction entered from SCATCORR Code<br>[Includes cavity return / see Sect.D.2.3] |
| M. | D C0RRED | Ni monitor response (c/s per gm) corrected to midplane (z=0)<br>and for neutron scattering (free-field value):<br>(col.J) / [(col.K)(1 + col.L)]<br><br>Average value and std. dev. are given below individual values<br>in Col.M: "AVERAGE=" / "std.dev.=" / "%std.dev.=" |

ANNOTATION OF THE QPRO SPREAD SHEET FLUDER-- Continued
[from Section D.2.1]
[Underlined labels indicate input information. * Obtain from Detector Assembly Worksheet]

| Col. | Label | Explanation |
|---|---|---|
| | | |

Free-Field Neutron Fluence at midplane (Z=0)

| Col. | Label | Explanation |
|---|---|---|
| P | K fact | K-factor (Ni fluence calibration factor from ctg. lab) |
| Q | DUMMY | not used [note: set=1; wall-return in SCATCORR] |
| R | T 1/2(d) | Ni monitor half-life in days |
| S | t(sec) | length of irradiation in seconds |
| T | LAMB.(1/s) | Ni monitor decay constant: <br> $\lambda$(Co58) = ln2 / (70.824)(3600) = 1.133E-7 |
| U | SATFAC | activation decay correction: <br> [1 - exp($-\lambda$T)] or entered from SATFAC code. <br> $\lambda$ from Col.T; T from Col.S [see Sect.B.2.1] |
| V | G | activation decay rate factor <br> G = (SATFAC)/T = (col.U) / (col.S) |
| W | FLUENCE | free-field neutron fluence at midplane <br> $\Phi$(z=0) = [k-factor] [D-corred avg.] / G <br> = (col.P) ["AVERAGE=" in (col.M)] / (col.V) |
| X | FLUENCE RATE | free-field neutron fluence rate at midplane <br> $\phi$(z=0) = (col.W) / (col.S) |

Free-Field Neutron Fluence at Detector Position

| Col. | Label | Explanation |
|---|---|---|
| A' | I.D. | *detector identification |
| B' | POS. | *detector position measured from midplane (mils) <br> (Z in mils from Detector Assembly Worksheet) |
| K' | GRADIENT | fluence at detector relative to midplane <br> $1 + (2.12E\text{-}5)(\text{col.B'})^2$ (see Sect. B.1.2) |
| N | FLUENCE | free-field neutron fluence at detector (n/cm$^2$) <br> (col.W)(col.K') |
| O | FLUENCE RATE | free-field neutron fluence rate at detector (n/cm$^2$,s) <br> (col.N)/(col.S) |

ANNOTATION OF THE QPRO SPREAD SHEET FLUDER -- Continued
[from Section D.2.1]
[Underlined labels indicate input information.]

| Col. | Label | Explanation |
|---|---|---|
| **Free-Field Reaction Probability** | | |
| A" | I.D. | detector identification (enter from col.A') |
| O' | FLUENCE RATE | free-field neutron fluence rate at detector (enter from col.O) |
| Y | SIGMA | reaction cross section in mb<br>[ENDF/B-V dosimetry file and ENDF/B-VI U235 fission spectrum] |
| Z | PHI*SIGMA | average reaction rate at detector<br>$\sigma\phi$ = (col.Y) (col.O') |

# C. THERMAL COLUMN ASSEMBLY AND IRRADIATION PROCEDURES

C.0. Major Precautions and Instructions
- 0.1 Memorandum For: NBSR Safety Evaluation Committee (June 1995)

C.1. Checklist for Assembly and Irradiation

C.2 Irradiation Procedures
- Irradiation Record and Preliminary Information Sheets

C.3. Thermal Column Assembly
- 3.0 Visuals
- 3.1 Source disk assembly
  - 3.1.1 thru 3.1.3
- 3.2 Detector capsule assembly
- 3.2.1 thru 3.2.2
- 3.3 Thermal column assembly and removal
  - 3.3.1 thru 3.3.4

C.4. Hardware and Large Component Identification and Storage (piece lists and photos)
- 4.1 Source and detector assembly
  - 4.1.1 thru 4.1.4
  - 4.1.5 storage site symbols
- 4.2 U235 fission source disks
- 4.3 Thermal column assembly
  - 4.3.1 thru .3.5
  - 4.3.6 storage site symbols
- 4.4 Photographs
  - 4.4.1 index
  - 4.4.2 photos

## C.0. MAJOR PRECAUTIONS AND INSTRUCTIONS

[sign to be mounted on thermal column door]

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C.0. MAJOR CAUTIONS AND INSTRUCTIONS
FOR
OPERATIONS AT THE THERMAL COLUMN

fac/cfsoper

(I) ALWAYS REPLACE CORRECT SHIELD PLUG IN THE INNER LEAD SHIELD BOX (SBI)
>plug SBIi for full open penetration: 2.7"dia.
>plug SBIc for reduction tube: I.87"dia.
>plug SBIh for CFS guide tube: I.63"dia.

(2) ATTACH THE LIFT TABLE TO THE THERMAL COLUMN DOOR WHEN DOING ANY WORK ON THE TABLE.

(3) DO NOT USE A WRENCH ON THE SHIELD BOX CLAMP (SB3D). HAND TIGHTEN THE PLATE

(4) BE CERTAIN THE PAWL ON THE LIFT TABLE CRANK IS ENGAGED AFTER CHANGING TABLE HEIGHT

(5) DO NOT USE STICKY TAPE ON LIFT TABLE UNLESS YOU INTEND TO REMOVE IT

C.0.1:

MEMORANDUM FOR The NBSR Safety Evaluation Committee

From: David M. Gilliam (6206), E. Dale McGarry, Jeffrey S. Nico, James M. Adams, Robert B. Schwartz, James A. Grundl, and Edward W. Boswell

Subject: Experimental Proposal for NBSR Thermal Column Operations by the Neutron Interactions and Dosimetry (NI&D) Group

EXPERIMENTAL PROPOSAL: #___________, June 30, 1995

TITLE: Thermal Column Operations by the NI&D Group

**LOCATION AND PURPOSE**

The thermal column (TC) is a roughly 2 meter cube of graphite within the reactor biological shield on the south side of the reactor core. Between the core and the graphite is about one meter of heavy water, 0.3 m of bismuth, and a sheet or "curtain" of boral which can be raised and lowered to turn on/off the diffusion of low energy neutrons into the graphite. The NI&D Group use the very-well thermalized neutrons from the thermal column for a variety of dosimetry experiments both inside the graphite and in external beams extracted from the graphite. This proposal will consider three categories of experiments: (1) internal cavity irradiations, (2) central port beam experiments, and (3) left port beam experiments. The NI&D Group does not use the radiography beam port on the right of the side of the TC nor the pneumatic tube irradiation facility near the top of the graphite, and this proposal does not include operations at those locations. This proposal also excludes large area radiography of paintings or other objects which are inserted by opening the biological shield door during reactor shutdowns.

**DESCRIPTION**

(1) Internal Cavity Irradiations

The internal cavity experiments include (a) thermal neutron irradiations, (b) capture gamma irradiations, (c) cavity fission source irradiations, and (d) irradiations in the Intermediate-Energy Standard Neutron Facility (ISNF). The cavity is a spherical air-filled void in the graphite with a diameter of 0.3 m. The thermal neutron fluence rate inside this cavity is of the order of $2 \times 10^{11}$ n cm$^{-2}$ s$^{-1}$ with the boral curtain up and about $1 \times 10^{8}$ n cm$^{-2}$ s$^{-1}$ with the curtain down. (All fluence rate levels are given for the reactor at 20 MW). A variety of access plugs of various sizes permit insertion of the various experimental packages. Extensive documentation of these access

features is being prepared in report by J. A. Grundl under contract to the NI&D group. In all cases, openings of these access ports are performed with the boral curtain closed, with a beam stop supported by the adjustable height table (see Fig. 1) in place to limit high-radiation conditions to the immediate area of the table top, and with various specially designed tools to accomplish the necessary manipulations without getting hands or any other body parts directly into a beam. Experimenters wear pocket chambers, gamma/beta/neutron TLD dosimeter badges, and finger dosimeters (if high doses to the hands are possible under unusual conditions) when inserting or removing these irradiation packages. A health physicist monitors the radiation outside the enclosed work area and limits personnel access to the nearby area when the largest rectangular plugs are removed for insertion or removal of the ISNF assembly. A radiation survey is made to check all objects extracted from the cavity at the end of an irradiation, and these objects are promptly transferred to storage shields and counting laboratories. The capture gamma irradiations, cavity fission source irradiations, and ISNF irradiations frequently involve residual radioactivity with exposure levels of greater than 100 mR/hr at contact. These very active objects are transferred to a lead and concrete shield just to the south and east of the TC enclosed area, against the south wall of the confinement building. The immediate area involved in these transfers will be roped off and access will be restricted to that area for a few minutes when these high activity objects are transferred to storage.

(2) Central Beam Port Experiments

The central beam port extracts neutrons from the rectangular cavity described above. At the biological shield face this beam has a fluence rate of $8 \times 10^{7}$ n cm$^{-2}$ s$^{-1}$ with the curtain fully raised. If the experimenter wishes to leave the beam experiment running unattended, then the beam area will be blocked off by temporary barriers and clearly posted to prevent inadvertent exposure of some other person who might enter the area. Any high radiation area will be appropriately posted and controlled.

(3) Left Port Beam Experiments

The left beam port extracts neutrons from the face of the graphite and produces a much less intense beam than the central port. The fluence rate at the biological shield face of the left beam port is about $1 \times 10^{5}$ n cm$^{-2}$ s$^{-1}$ with the curtain fully raised. This beam port is used mostly for radiation protection dosimetry and most tests are carried out with the experimenter in attendance. The open beam gives a neutron dose of the order of 100 mrem/hr at the usual test position, about six feet from the biological shield face. If the experimenter wishes to leave the beam experiment running unattended, then the beam area will be blocked off by temporary barriers and clearly posted to prevent inadvertent exposure of some other person who might enter the area. Any high radiation area will be appropriately posted and controlled.

**Shielding Considerations**

The enclosed work area is surrounded by 0.3 m thick, heavy-concrete shield walls.

A lead glass face shield is mounted on one side of the adjustable table and lead brick shields are set up as necessary to reduce exposure when working on irradiated pieces.

Beam stops are always made thick enough to reduce the exposure to below 20 mR per hour at the hot spot on the beam axis.

**Boral Curtain Control and Position Indication**

The boral curtain is controlled from a box on the confinement building south face. One button raises the curtain, the other lowers it. A green light indicates that the curtain is fully down, a red light indicates that the curtain is fully up, and a yellow light indicates that the curtain is in some intermediate position. The boral curtain will not be operated without permission from the control room. The control room will be notified of any changes to the shield configuration which could result in creation of a high radiation area if the curtain were raised. When the configuration is such that a hazardous situation could arise from raising the boral curtain, then the boral curtain control will be locked and tagged until that possibilty has been eliminated. It is noted that the closing and locking of the boral curtain must not be permitted to create a false sense of securtity, because beams of fast neutrons and gamma-rays can still emerge from the beam ports even with the curtain down.

**SAFETY CONSIDERATIONS**

The work area is enclosed by heavy-concrete shield walls to keep the dose levels outside the work area below 2 mR/hr.

Experimenters wear pocket chambers and gamma/beta/neutron TLD dosimeter badges always, and finger dosimetry (if necessary) when handling highly radioactive objects or manipulating shield plugs for high-level beams.

Beam stops are kept in place any time a beam plug is removed, because fast neutron and gamma-ray doses can be significant even with the curtain closed.

**Repair and Maintenance**

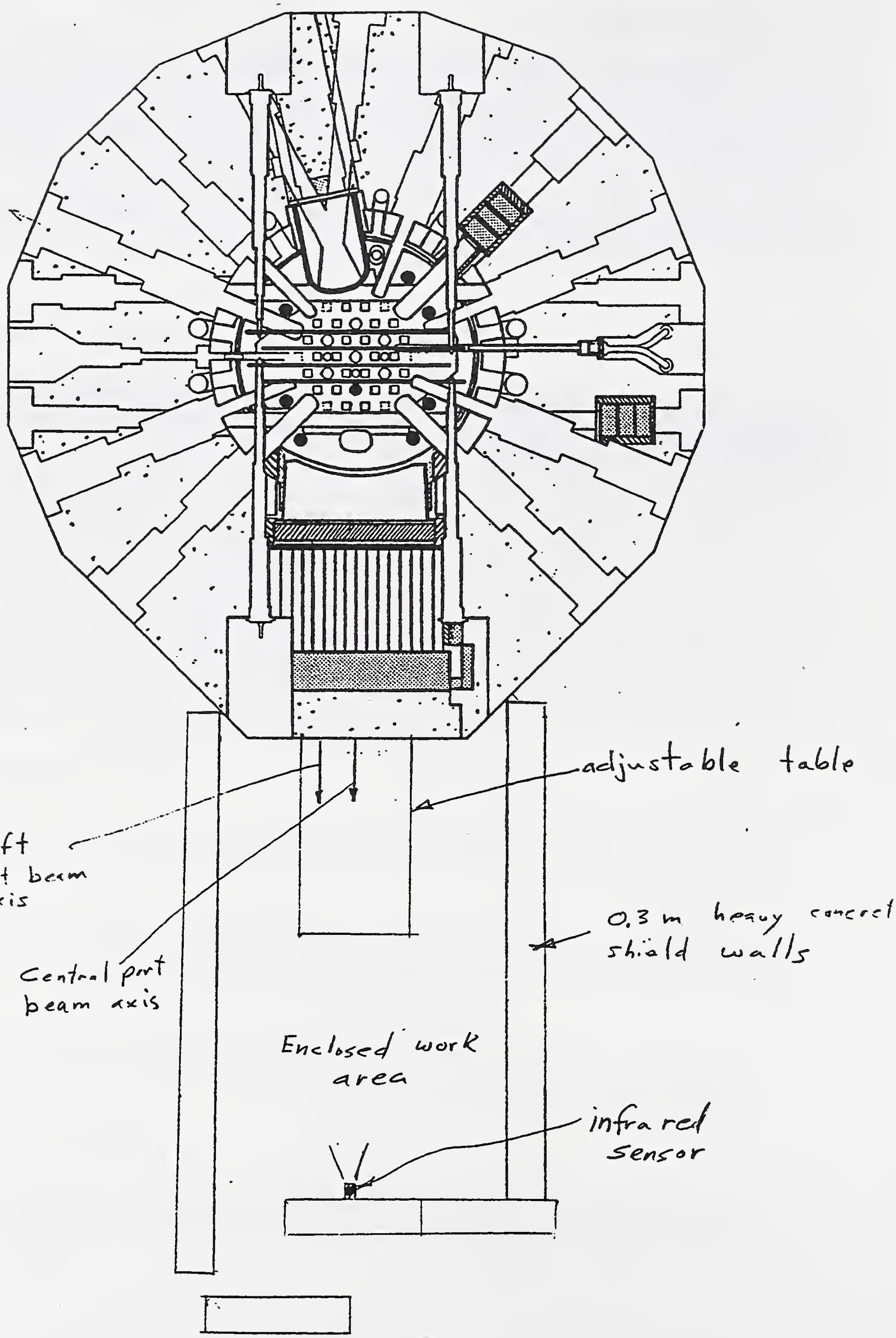
Repair and maintenance are done during reactor shutdowns, because the boral curtain is not a fully effective shutter, but only reduces thermal neutron levels by a factor of about 2000.

### Fire and Other Emergencies

The name, address, and phone numbers (work and home) of two contact persons will be supplied to Reactor Operations with a copy posted in the TC area. In addition, detailed procedures to shut off the beam, experimental equipment, and utilities will be posted at the control box and within the TC enclosed work area. No samples or instruments which present a fire hazard are anticipated. Special samples or apparatus which fall outside the parameters of previously approved experiments would be submitted to the SEC for approval.

## CONCLUSIONS

The design, construction, and operation of the Thermal Column do not involve any unreviewed safety issues. There are no failure modes that can affect other experiments or reactor operations.


adjustable table
Left port beam axis
Central port beam axis
0.3 m heavy concret shield walls
Enclosed work area
infrared sensor

## C.1. CHECKLIST FOR THERMAL COLUMN ASSEMBLY AND IRRADIATION (03March97)



### 1.1 Preparations At Central Penetration

> Roll-Away Table (WT) at correct height and secured to studs
  --check engagement of pawl in sprocket
  --check boral curtain down (green light on at wall)
> Penetration reduction tube (SB1b) and CFS guide tube (SB1d) in inner shield box (SB1). The (the latter need not be attached)
> Steel shield plug SB1h in place
> Shield box SB3 in place with shield plug SB3a

### 1.2 Transfer and Assembly of CFS

> Portable lead shield (PSa) on yellow roll table (RT) at shield cave
> Open shield cave, SC, and inner shielded section, SCa
  --technique for opening shield cave door: set steel bar close to floor and an inch or so under the protrusion of (orange) dolly axle (either side); lift bar and push door along runway; repeat until door is in motion
  --open sliding door to inner shield, SCa
  --check radiation level at source tabs
> Slide source insertion tube (SI) into PSa
  --do not handle near source tabs
  --remove stop ring S1a1 if necessary
> Place PSa on dolly (PSb) at body shield (BS) w/ glass brick (GLB)
> Assembly of detector capsule tube (CI) into source insertion tube (SI)
  --withdraw capsule holder into cage and slide CI into SI
  --capsule holder cap facing source tab SIb2
  --check stop clearance and bottom and top closure
  --attach CI to SI w/ 6-32 screw and insert push rod w/ capsule
  --attach push rod with latch and screw

> Call Health Physics
> Remove shield plugs SB3a and SB1h
> Insert CFS assembly into shield box SB3 using the portable shield
> Attach stop ring S1a1 and assembly pull rod (CIc)
> Insert CFS full into cavity
> Insert shield plug SB3a into shield box
> Roll outer shield box (SB2) into place w/insert plug SB2b
> Stack lead bricks and white polythene blocks across face of penetration

C.1. CHECKLIST FOR THERMAL COLUMN ASSEMBLY AND IRRADIATION [continued]
(03March97)

## 1.3 CFS IRRADIATION

> Notify reactor control room and get key for curtain control box
> Sign clipboard w/ contact name and number
> Raise boral curtain to start irradiation
--put up signs at curtain control box: "curtain up" or "Do Not Change Position of Boral Curtain"
--check radiation levels at thermal column door
> Lower boral curtain to end irradiation
--while CFS is in the Thermal Column, set large sign: "Do Not Raise Boral Curtain"
--notify reactor control room not to release key to maintain control of thermal column
> Fill out "Irradiation Record" sheet
--start of irradiation: local time at start of curtain up
--end of irradiation: local time at start of curtain down

## 1.4 REMOVAL OF DETECTOR CAPSULE, CI
(after 0.5h or longer depending on length of irradiation)

> Unstack lead bricks and roll shield box SB2 onto work table
> Remove shield plug SB3a and pull CFS out to face of SB3
--measure emerging radiation level
> Disconnect pull rod and capsule assembly attachment stud
> Unlatch push rod (CIb) and withdraw to stop
> Remove detector capsule assembly (CI) and check radiation level
> Replace shield plug SB3a and roll SB2 back into place

## 1.5 REMOVAL OF SOURCE INSERTION TUBE, SI
(8h to 48h after EOI depending upon length of irradiation)

> Roll shield box SB2 onto work table
> Pull SI out to edge of SB3 with pull hook, SITd
> Bring up portable shield (PSa,b) and pull SI into shield
> Roll (or carry) PSa to heavy duty roll table (RT)
> Move RT to shield cave and stow SI in inner lead enclosure
> Replace shield box SB2 and secure center penetration
> Notify reactor control room that thermal column operations are finished, return key

## C.2. THERMAL COLUMN IRRADIATION PROCEDURES 

1. General Instructions Related to Radiation Safety

>> Follow instructions in "Memorandum For The NBSR Safety Evaluation Committee" Title: "Thermal Column Operations by the NI&D Group." A copy of a 30June95 version is in Section C.0.1

>> Consult with Group Leader regarding latest requirements for
a. radiation and area warning signs, and ropes to be put up
b. shield wall and placement
c. motion warning system for area inside shield walls
d. operation of boral curtain with key at south wall near large access door
e. notification of reactor operations regarding boral curtain operation including experimenter in charge of CFS irradiation

2. Irradiation Time History

>> For detectors with half-life greater than about one hour
--end-of-irradiation (EOI): time when the curtain "down" button is pressed
--start-of-irradiation (SOI): time when curtain "up" button is pressed

>> For short half-life detectors the reactor power log from reactor operations may be satisfactory. Alternatively, the SATFAC code has been successfully coupled to a fission chamber operating in one of the penetrations of the thermal column door.

>> A profile of Thermal column irradiations using the boral curtain is shown on following page with title: "Curtain Operation and Timing of Irradiations." Time fiducials are defined for irradiations with and without a fission chamber monitor.

3. Summary of Thermal Column Operation
(Detailed instructions are in Section C.3 / see also check list in Sect. C.1)

>Assemble foils into the cadmium detector (CC) capsule and record all dimension information
>Insert into the detector capsule holder (CIb) at the tip of the detector capsule insertion assembly (CI). Snap on cover and withdraw holder.
>Insert CI into the source insertion tube (SI) and attach with screw. Insert push rod (CIb) and secure with clamp.
> Insert SI into thermal column with outer shield boxes (SB2, SB3) removed. Replace shield boxes.
> Notify reactor control room and put up signs at curtain control box
> Raise and lower boral curtain to begin and end irradiation.
(control box key is in reactor control room)
--start irradiation (SOI): when the "up button is pressed
--end of irradiation (EOI): when the "down" button is pressed

4. Irradiation Record and Preliminary Information Sheet following are from Sect. D.1.3

IRRADIATION RECORD [From D.1.3 / 6-29-92] fac/cfsoper
[protocol for irradiation designation after 1986:
U,month,date,year, sample: U011391 for irrad on Jan. 13, 1991]

1. Irradiation i.d:

Exposure: megawatt x hours = MW-hr

2. Nominal Neutron Fluence at Z = 0:

3. Materials Irradiated and Capsule Position:

i.d:

Z:

4. <u>Source Assembly</u> i.d. R/h @ 10cm, time

Top Source Disk CV-

Bottom Source Disk CV-

Source separation distance: D = f + 118mils =

Detector capsule facing tab SIB___

5. <u>Irradiation Interval</u>

SOI (start boral curtain up):

Date: Time: EST

EOI (start boral curtain down):

Date: Time: EST

[Length of irradiation: T = EOI - SOI = ]

Irradiation Operator: ______________________ Date: ___________

Checked by: ______________________ Date: ___________

[from D.1.3]

PRELIMINARY INFORMATION FOR CAVITY FISSION SOURCE IRRADIATION

(Test Report to follow) cfs/oper

1. Irradiation i.d. (see previous for protocol)

Requestor/User:

2. End-Of-Irradiation (EOI): Date: Time: (EST)

Length of irradiation:

3. Materials Irradiated

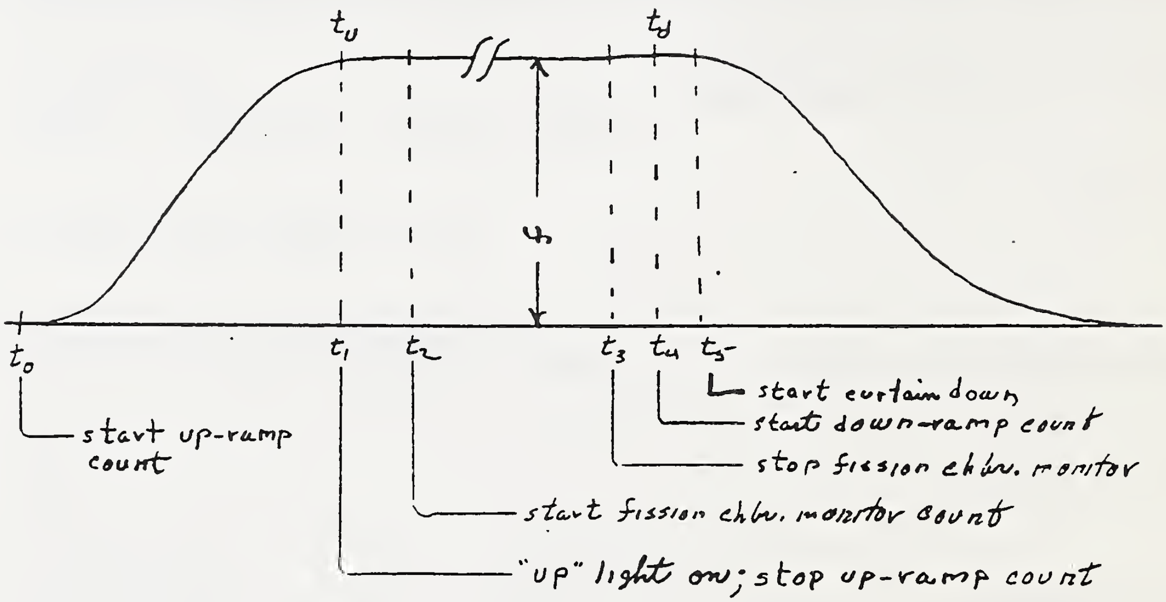
i.d:

Time History
Correction, C:

Nominal
Neutron Fluence:

Calculated
Cross Section:
(ENDFB-VI dosimetry file)

4. Contact:




>Time fiducials w/o fission chamber monitor

$t_u$ = curtain full up (red light on) -- up time = 48s

$t_d$ = start of curtain down (red light off) -- down time = 49s

End-of-Irradiation (EOI) = $t_d + \Delta t_d$

Start-of-Irradiation (SOI) = $t_u - \Delta t_u$

Irradiation Interval = $t_d - t_u + (\Delta t_d + \Delta t_u)$

0.3min

---

> Time fiducials w/ fission chamber monitor (incomplete)

to=
t1=
t2=
t3=
t4=
t5=

F = total fission monitor count between tu and td
f = average full-power fluence rate

Simplified time history outside of tu and td

## C.3. Thermal Column Assembly

3.0 Visuals

3.1 Source disk assembly
.1.1 description of source disks
.1.2 mounting of source disks into source tabs and removal
.1.3 source disk storage and handling

3.2 Detector capsule assembly
.2.1 description of detector capsule insertion tube (CI)
.2.2 insertion and removal of detector capsule

3.3 Thermal column assembly and removal
.3.1 assembly of detector capsule tube (CI) into source insertion tube (SI)
.3.2 CFS insertion into thermal column
.3.2.1 shield box preparation
.3.2.2 CFS insertion
.3.3 removal of detector capsule assembly (CI)
.3.4 removal of source insertion tube (SI)

## C.3. THERMAL COLUMN ASSEMBLY

C.3.0 Visuals

Photos and diagrams are called out at the beginning of each subsection. They are located in this document as follows

## C.3.1. Source Disk Assembly

### 3.1.1 Description of Source Disks

Two pairs of source disks are in use (CV-5 thru CV-8). One pair is for low level irradiations and the other for higher level irradiations. Each source disk (0.625"dia.x0.006" thick) is made up of two 3 mil thick enriched uranium metal foils wrapped in 0.0015" aluminum foil. The total weight of a wrapped source disk is about 0.60g and the total thickness is 0.015." The disks, with designation CV-5 etc. marked on the aluminum wrap, are stored in the shield cave--see B.2. The source disks will swell and distort after long use.

During operation in the thermal column with the reactor at 20MW, the fission neutron source strength of the two disks is about $3x10^{11}$n/s corresponding to a heat generation rate of about 2 watts per source disk.

### 3.1.2 Mounting of Source Disks into Source Tabs and Removal

The source disks are held in the source tabs by a twist lock ring. Source disk assembly is always done from behind the body shield (BS) and glass brick (GLB) with the source tube (SI) in the portable lead shield (PSa,b,c). Depending upon when they were last irradiated, the source disks will show radiation levels at 10 cm of from 10R/h to 60R/h.

The source disks are kept in the lead cup (LC) which is normally stored in the lead shield cart. The source disks are only removed from the source tabs for a change of irradiation level. The SI assembly w/source disks is stored in shield cave.

<u>Procedure:</u>

Always work from behind body shield (BS) and glass viewing brick(GLB). Do not leave source disks exposed outside of the portable shield except when carrying out this procedure.

Push source tube (SI) thru portable lead shield PSa,b,c until the tabs are resting face up on the front bracket.

Assembly: Use tweezers to place the source disk into source tab 1 with smooth side down. Insert twist lock ring SIc with tweezers and twist into slot with source disk removal tool SITc. <u>Be sure the twist lock ring turns in snugly.</u> If not place 5 mil aluminum disk on top of the source disk to achieve a snug fit. Turn the source tube around and repeat for source tab 2. Record source disk number in each source tab.

Disassembly: Remove twist lock ring (SIc) with source disk removal tool (SITc). Remove source disk by turning SI upside down and tapping the source tab until the source disk falls out, or push out with tweezers.

3.1.3 Source Disk Storage and Handling

**When not in use the source disks are kept in the shield cave. Always check the radiation level of the source disks before handling. Use the lead cup or the portable lead shield PSa as a carrier when moving source disks to the assembly area. Wear glasses.**

## C.3.2. Detector Capsule Assembly

### 3.2.1 Description of Detector Capsule Insertion Tube(CI)

The detector capsule insertion assembly (CI), which fits inside of the source insertion tube (SI), is fitted with a push-pull rod which allows the capsule holder (CIa) to be moved in and out of the source tabs. The proper orientation of the source capsule holder is indicated at the far end of CI by the position of the set screw on the rod stop. Set screw up indicates the lid of the the capsule is up.

The CI assembly is held in SI with a 6-32 screw stud which threads into the end collar on CI thru a hole in SI. A simple latch and screw at the end of CI holds the push-pull rod in place.

The capsule holder consists of an open cup attached to the push rod and a snap-on cap. The cap is slotted so as to push on in one orientation only. Do not snap the cap onto the empty holder. A dummy detector capsule (SITb) can be used as needed.

### 3.2.2 Insertion and Removal of Detector Capsule

The detector capsule (CC) consists of a cadmium cover and cap which is kept in a lucite holder with a screw on lid when it is loaded. The detector capsule cup and cover are not attached. The detector assembly inside will spill out if the cadmium cup is not kept upright or held together during handling.

Installation into capsule holder: Push the detector capsule holder rod (CIb) out of its cage. Orient with the cap up. Remove the holder cap with the cap removal tool (CITa) by resting the capsule holder in the CITa and pressing on the dummy capsule inside. Remove dummy capsule. (The capsule holder cap should never be pushed on w/o a real or dummy capsule inside).

Place the detector capsule inside of the holder with the cadmium cover facing up. Replace the capsule holder cap (with slot in properly orièntated) by a firm pressure all around. Check to see that the assembly is tight.

Measure the height of the assembled capsule holder with a micrometer to see that the top and bottom are parallel to a few thousandths of an inch. Record the average of the readings on the "Detector Assembly Worksheet" (Section B.1). The nominal value is 0.370". Withdraw capsule holder back into cage to prevent bending.

Reverse the above procedure for removal of detector capsule.

## C.3.3. Thermal Column Assembly and Removal

### 3.3.1 Assembly of Detector Capsule Tube (CI) Into Source Insertion Tube (SI)

Withdraw capsule holder into cage. Work from behind the body shield using the glass brick for viewing. Slide CI into SI with the latter in the portable shield (PSa,b,c).

Note: (1) Stop ring S1a1 must be removed for SI to fit into the portable shield.
(2) The distance from stop ring marks to axis of the fission disks should be 32.25".

Orient capsule properly relative to the tabs (holder cover facing tab SIb2). Push the capsule holder between the source tabs so that the cap is up against the ring segment stop. In this position the rod stop at the far end of CI should show a gap of less than a 1/16."

Check to see that the other ring segment stop for the holder cup shows nearly equal clearance on both sides. Rotate the SI 90° and examine the closure of the capsule holder and the source tabs. Openings around the edges should not be more than 0.015". Attach CI to SI with 6-32 screw stud and latch push rod with hand screw--see C.1.

==========================================

The following operations are carried out by one person standing on RH side of the lift table and close to face of thermal column door with a minimum of body exposure to the radiation emerging from the 12"x12" opening. When the inner shield plug SB1h is out and the emerging radiation beam is about 20 R/h. With the CFS inserted and middle shield box, SB3, in place but without closure plug, the radiation level at the face of the opening is about 0.5 R/h.

==========================================

### 3.3.2 CFS Insertion into Thermal Column

#### 3.3.2.1 Shield Box Preparations

If not in place, roll the lift table up to the thermal column door and attach loosely to the two studs on the door. Crank table height to match the bottom of the 12xl2 penetration and tighten the stud nuts. Crank is on left hand side of table.
Be sure the pawl is engaged into sprocket to hold table height.

CHECK TO SEE THAT THE BORAL CURTAIN IS DOWN. This is indicated by a green light at the curtain control box on back wall to the right of large reactor access door. Current system has a motion detector and beam on/off indicator.

Working from the side of the table and close to the thermal column door, use pull rods SBRa to roll shield boxes SB2 and SB3 out onto the lift table. The front face of SB3 should be kept as close to the front face of the door as is convenient. Remove lead closure plugs from SB2 and SB3 if in place.

NOTE: The radiation field at the central penetration with the shield boxes SB1 and SB2 out is up to 0.5 R/h. ALWAYS CHECK RADIATION LEVELS WHEN SHIELD BOXES AND SHIELD PLUGS ARE WITHDRAWN.
The inner box, SB1, is NEVER withdrawn for Cavity Fission Source operations.

If the penetration reduction tube SB1b is in the inner shield box SB1 with the shield plug SB1h in place, skip to "Remove shield plug SB1h."

--------------------------------------------------------------

Remove the shield plug, SB1c, from the inner shield box SB1.

NOTE: A radiation beam of a few R/h is emerging from the thermal column.

Insert penetration reduction tube SBlb into SBl. It is attached to the SBl with a screw thru the the top of the SBl penetration tube. Insert shield plug SB1h.

--------------------------------------------------------------

Remove shield plug SB1h.

NOTE: A radiation beam of a few R/h is emerging from the thermal column.

Install the CFS guide tube (SB1d) into the penetration reduction tube (SBlb) of the inner lead shield box (SB1).
[Optional: Attach SBld to SBl with screw at the face of SB1b.]

Roll shield box SB3 (with lucite neutron shield (SB3c) hung on the front) up against shield box SB1. Insert shield plug SB3a if CFS insertion does not follow immediately.

### 3.3.2.2 CFS Insertion

Roll the portable shield with CFS up close to shield box SB3, remove shield plug and partially insert the CFS. Remove portable shield.
Attach stop ring S1a1 between marks at the end of CI.
Attach threaded pull rod CIc to the end of the push rod CIb.

Insert CFS into thermal column with pull rod CIc so that the stop ring is up against guide tube SB1d. Replace outer shield box SB2 and insert shield plug SB2b.

Note: (1) The portable shield can be dispensed with if the radiation level of the fission disks is below about 10R/h.
(2) Option: Use push rod CIb directly instead of pull rod CIc to insert CFS4. This must be done with the outer shield box SB2 withdrawn onto the lift table.

Stack lead bricks so as to bring the radiation level down to 30mr/h when the boral curtain is up. To avoid interference with other experiments, it may be necessary to place white polyethylene blocks on the table when the fission source is in operation.

### 3.3.3 Removal of Detector Capsule Assembly (CI)

Note: In normal operation, the detector capsule is removed at about 30 minutes after end-of-irradiation.

Remove shield box SB2 and closure plug SB3a.
Pull CFS assembly out approximately to the front face of SB3.
Disconnect pull rod (CIc) and detach CI from SI by removing 6-32 attachment stud.
Unlatch push rod (CIb) and withdraw to stop.

Remove CI only keeping hands out of the emergent beam.
Check radiation level of detector capsule. Push CFS assembly in with closure plug SB3a.
Roll shield box SB2 w/ lead plug back into place.

Notify reactor control room to keep boral curtain down until thermal column is released for general use. Put up sign at control box: "Do Not Raise Curtain."

Check radiation level and decide whether to delay disassembly.
Disassemble C1b with capsule removal tool (CITa) to recover detector capsule
-- see Section C.3.2.2.

### 3.3.4 Removal of Source Insertion Tube (SI)

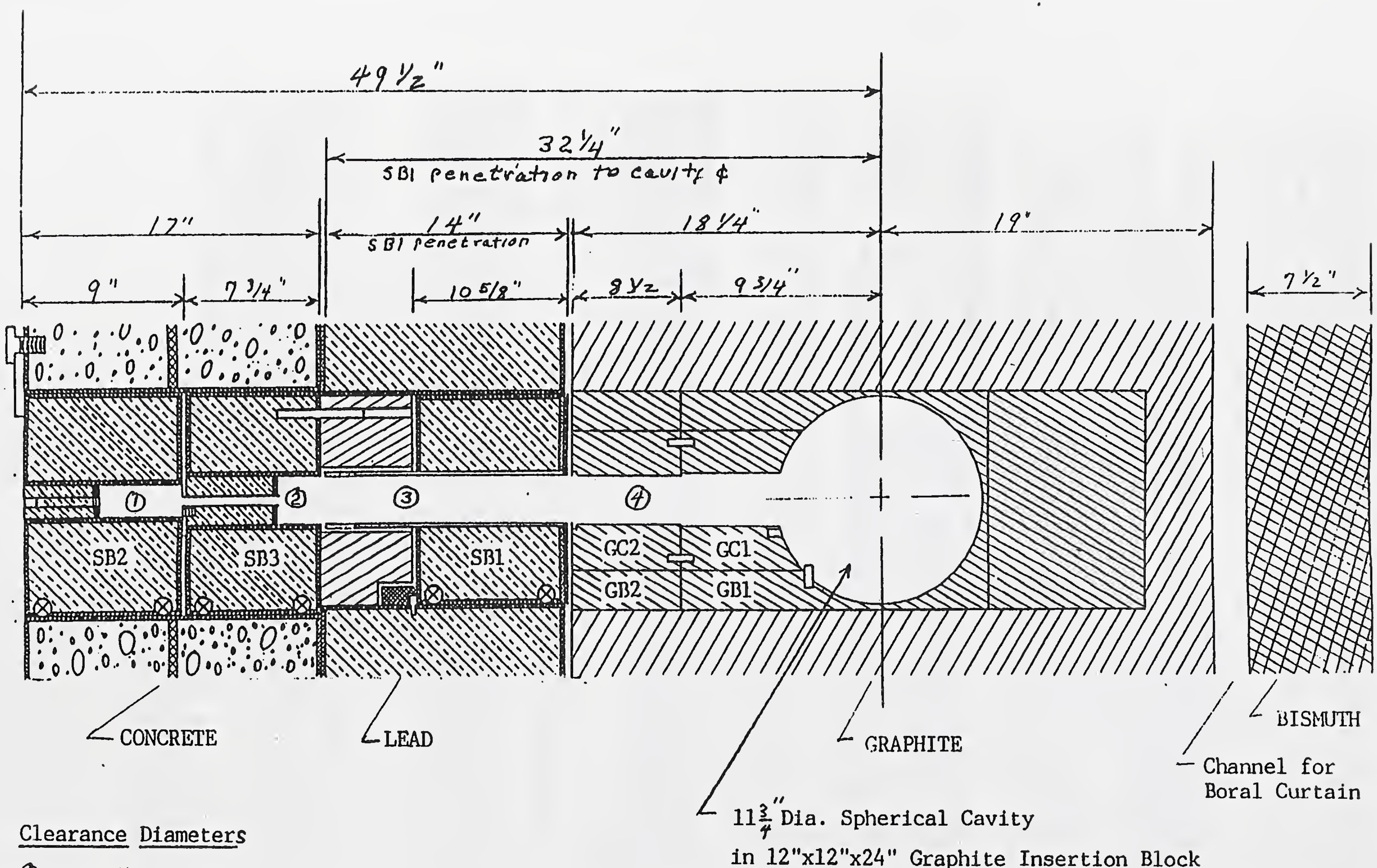
The CFS is always left in the thermal column for a period of time to cool down. This may be anywhere from 8h to 48h depending upon thermal column scheduling and the length of the irradiation. The removal of the SI and transfer to the shield cave should be done with the portable shield (PSa,b).

NOTE: Radiation levels of source disks may be as much as 70R/h.

Remove shield box SB2 and remove stop ring from SI. Roll portable shield (PSa,b) up to SB3 with about 4" clearance. Remove shield plug SB3a and pull SI out with pull hook. Reach around the front and push SI thru the portable shield until it can be handled from the back. Move SI into the portable shield such that the source disks are at the center. Roll portable shield onto roll table (RT).

Open left side of storage cave including inner lead enclosure roll door (SCa). Carry portable shield to the open storage cave. Working from the side to minimize exposure, push SI into the cave and into the inner lead brick enclosure (SCa). Place a lead brick in front with sign that indicates hot source is inside. Close inner roll-door (SCa) and main cave roll-door (SCb).

Button up thermal column with all boxes and plugs in place. Indicate setup of inner box penetration on the "Log of Penetration Setup" (Sect. A.2.2).
Release thermal column to reactor control.

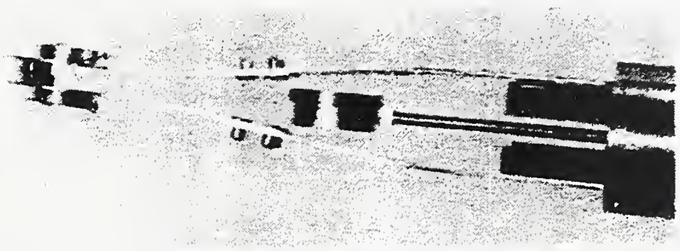


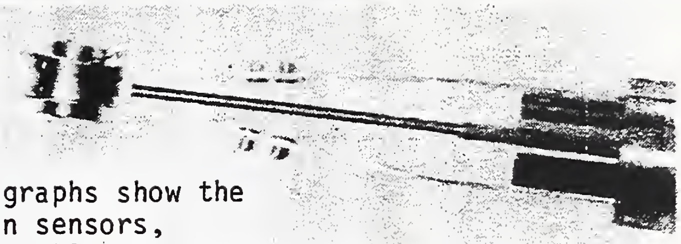

Clearance Diameters

1. 1.83"
2. 2.748"
3. 2.690"
   1.870" w/reduction tube, SB1b
   1.635" w/CFS guide tube, SB1d
4. 2.74"

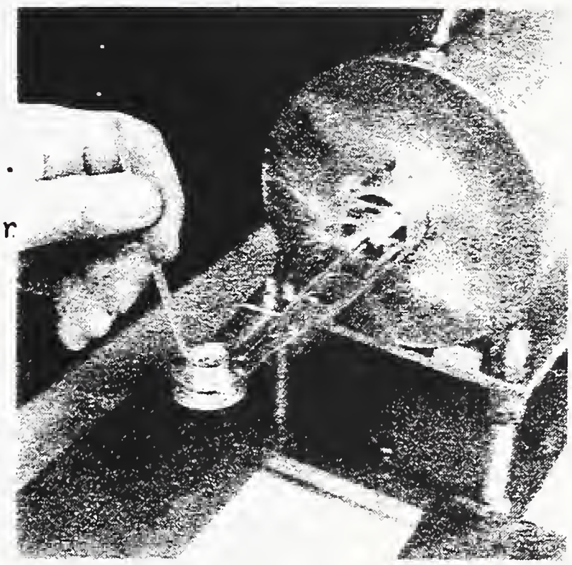
4-16-90

Fig.C3-1 CROSS SECTION OF CENTRAL PENETRATION WITH CAVITY ASSEMBLY





The above two photographs show the way in which neutron sensors, inside of a cadmium pill box, are reproducibly inserted between two highly radioactive fission disks.



The photograph to the right shows "cold" fission disks being mounted. The cylindrical assembly is a lead shield which will be used for their removal after the irradiation.

The photograph to the left shows the fission disks and cadmium-covered neutron sensors mounted inside of a graphite cavity, which will be inserted into the thermal column of the NBS Research Reactor.

Fig.C3-2 Source tab assembly

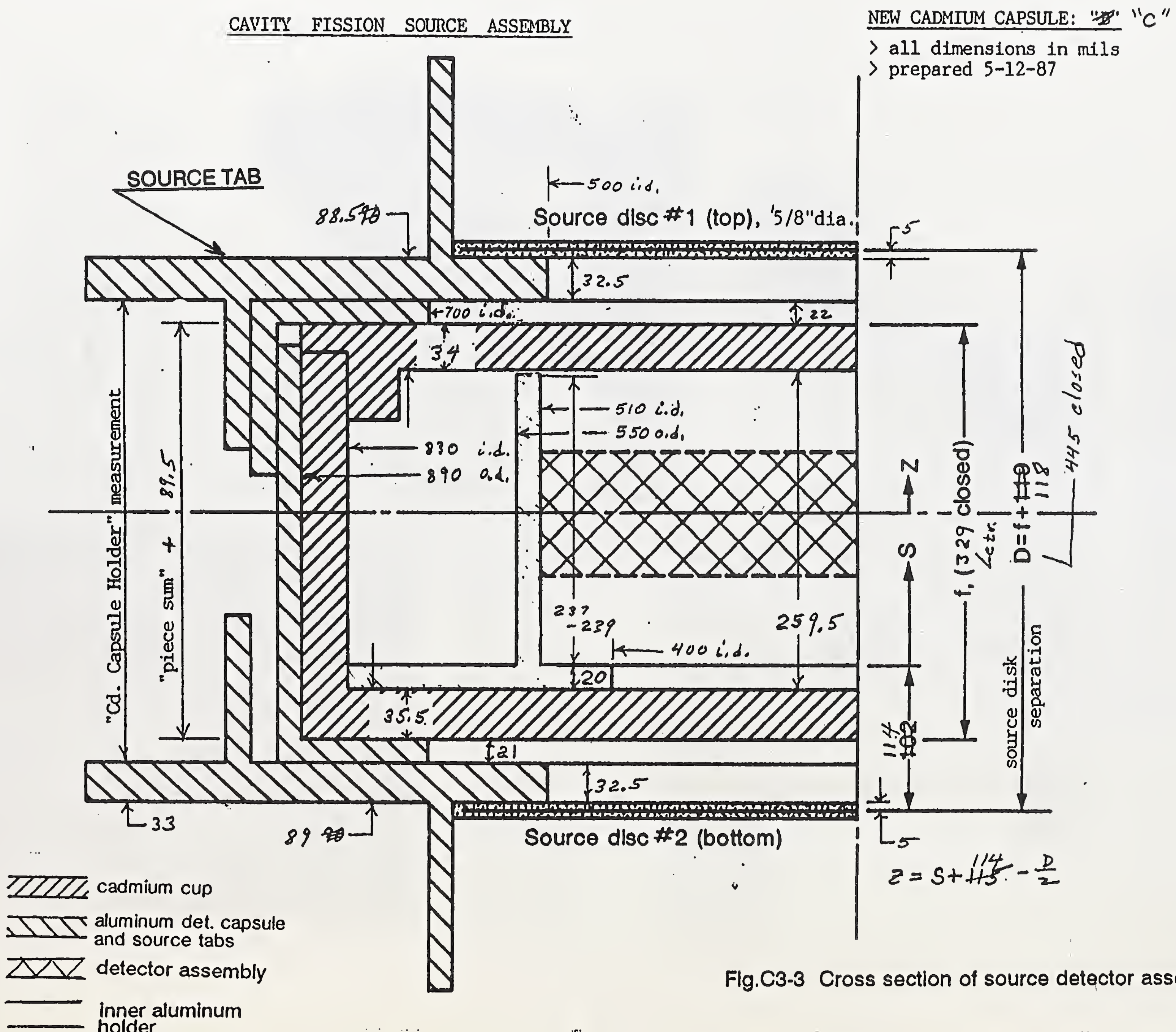



Fig.C3-3 Cross section of source detector assembly

# C.4. HARDWARE AND LARGE COMPONENT IDENTIFICATION AND STORAGE

## C.4. HARDWARE AND LARGE COMPONENT IDENTIFICATION AND STORAGE

[28March95] fac/cfsoper

### C.4.1. SOURCE AND DETECTOR ASSEMBLY

| | ident. symbol | store |
|---|---|---|
| **C.4.1.1 Source Insertion Tube Assembly (SI)** | | SCa |
| a. source insertion tube (1.635"o.d.) | SIa | |
| and stop ring | SIa1 | |
| (HS1) b. source mounting tabs | SIbl,2 | |
| c. twist lock rings (2) w/spacer disks | SIc1,2 | |
| d. source disks | CV5-CV10 | SCa |
| **C.4.1.2 Detector Capsule Insertion Assembly (CI)** | | SC1 |
| a. guide assembly for push rod | CIa | SC1 |
| b. push rod w/ stop, det. capsule holder & cap | CIb | SC1 |
| c. push rod extension | CIc | HS2 |
| **C.4.1.3 Peripherals Including Assembly Tools** | | |
| a. lead cup & cap for source disk storage | LC | SCa |
| b. capsule-holder cap removal tool | SITa | HS1 |
| c. detector capsule dummy | SITb | HS1 |
| d. source disk removal tool (SIc wrench) | SITc | HS1 |
| e. SI pull hook | SITd | LT2 |
| **C.4.1.4 Detector Capsule and Assembly Tools** | | |
| a. cadmium capsules (3 scribed A, B, C) | CC(A,B,C) | HS5 |
| b. inner hats for disk shaped detectors | Ca | HS4 |
| c. spacer rings | Cb | HS4 |
| d. detector stack disassembly mandril | Cc | |
| e. lucite detector capsule holder | Cd | HS1 |

### C.4.1.5 Storage Sites

Summary:

> Source insertion tube (SI) w/ hot fission disks: inner shielded section of the shield cave (SCa)
> Detector capsule insertion assembly (CI): top shelf of shield cave (SC1)
> Most source-detector assembly tools: lucite box at the lift table (HS1)
> Detector capsule assembly hardware: cabinet in Rm.A154
> Cadmium capsules: lead shield on work table, Rm.A158

| Storage Sites: | Symbol |
|---|---|
| >lift table shelves [LT1(top), LT2(middle), LT3(bottom) | LT1-3 |
| >shield cave shelves [SC1(top)--SC5(bottom] | SC1-5 |
| >inner shielded section of the shield cave on SC2 | SCa |
| >lucite box marked "Cavity Fission Source" at lift table (on LT1) | HS1 |
| >drawer marked CAVITY FISSION SOURCE / ISNF in 4-drawer wheeled cart | HS2 |
| >table at wall near th.col. curtain control | HS3 |
| >cabinet in Rm.A154, open box marked "cavity fission source assembly" | HS4 |
| >work table in Rm.A158, lead brick shield | HS5 |

C.4.2 $^{235}$U Fission Source Disk Inventory

| Designation | Components (5/8"diax3 mil thk) | wt. | Wrapped Source (1.5 mil Al) wt. | thkness | date assembled |
|---|---|---|---|---|---|
| CV-3 | 25-3-1 | | | | 9-22-82 |
| | 25-3-2 | 275 mg | | | |
| CV-4 | 25-3-3 | 273 | | | 9-22-82 |
| | 25-3-4 | 271 | | | |
| CV-5 | NH9-2 | 270 | 0.596g | 0.0105(ctr) | 9-3-85 |
| | NH9-3 | 266 | | 0.015(edge) | |
| CV-6 | NH9-4 | 275 | 0.598g | 0.0102(ctr) | 9-3-85 |
| | NH9-5 | 271 | | 0.015(edge) | |
| CV-7 | NH9-6 | | 0.577g | 0.0083(ctr) | 12-12-86 |
| | NH9-7 | | | 0.013(edge) | |
| CV-8 | NH9-8 | | 0.580g | 0.0085(ctr) | 12-12-86 |
| | NH9-9 | | | 0.013(edge) | |

==================================================

| | hand trimmed dia. (3 mil thk) | dia. | U-disk wt. | | |
|---|---|---|---|---|---|
| CV-9 | NH9-10 | 0.58" | 0.458g | 0.0123(ctr) | 6-17-92 |
| | NH9-11 | 0.60 | | 0.017(edge) | |
| CV-10 | NH9-12 | 0.60 | 0.469g | 0.012(ctr) | 6-17-92 |
| | NH9-13 | 0.60 | | 0.018(edge) | |

### C.4.3 Thermal Column Assembly
[revised: 19Feb95]

#### C.4.3.1 Thermal Column Shield Boxes (3 on rollers)

| Item | Ident. Symbol | Store |
|---|---|---|
| .1.1 Lead shield box (inner) [12"x12"x10-5/8" w/inner cylinder] | SB1 | |
| a. 8" dia. inner cylinder (w/2.690" dia. penetration) | SB1a | |
| b. penetration reduction tube w/ screw (1.870" dia. x 14.0"long) | SB1b | LT2 |
| c. lead shield plug and handle (1.81" dia.) | SB1c | LT3 |
| d. guide tube & stop for CFS insertion w/ screw (1.635" i.d.) | SB1d | LT2 |
| e. shield bar | SB1e | |
| f. platform with guides and end stop, side bars | SB1f | LT3 |
| g. cinch pins (2) for box and cylinder | SB1g | |
| h. steel shield plug & handle (1.63" dia.) | SB1h | LT3 |
| i. lead shield plug & handle (2.7" dia.) | SB1i | LT3 |
| j. steel shield plug for SB1b | SB1j | LT3 |
| .1.2 Shield box (outer) [15"x15"x9" w/ cylinder] | SB2 | |
| a. cylinder (8.7"o.d. w/1.83" dia. penetration | SB2a | |
| b. lead closure plug (1.77"dia.) | SB2b | LT3 |
| c. shield box clamp | SB2c | LT2 |
| .1.3 Shield box (middle) [15"x15"x7-3/4" w/2.748" dia. penetration] | SB3 | |
| a. lead closure plug w/ 0.825" dia. penetration | SB3a | LT3 |
| b. steel plug for lead closure plug | SB3b | LT3 |
| c. lucite neutron shield (12.5"x11.25"x4" detachable) | SB3c | |

#### C.4.3.2. Insertion and Removal of Shield Boxes and Graphite Cavity
[HARDWARE IN THIS SECTION NOT USED FOR CAVITY FISSION SOURCE OPERATIONS]

| Item | Ident. Symbol | Store |
|---|---|---|
| .2.1 Shield Boxes (SB) | | |
| a. pull rods w/(1/2-13 thd.) (3) | SBRa | LT2 |
| b. removable platform with roller guides | SBRb | LT3 |
| c. lead bricks (2) & spacer block | SBRc | LT3 |
| d. push tube & bar | SBRd | SC5 |
| e. table track -- right | SBRe | LT3 |
| f. " " -- right back | SBRf | LT3 |
| g. " " -- left front | SBRg | LT3 |
| h. " " -- left back | SBRh | LT3 |
| track attachment screws | | HS2 |
| i. pulley assembly and pull cord | SBRi | HS2 |
| .2.2 Inner Shield Cylinder (SB1a) | | |
| a. inner runway | SCRa | LT3 |
| b. outer runway w/ risers(2), stop and cinch pins(2) | SCRb | LT3<br>HS2 |
| c. cradle with rollers | SCRc | LT3 |
| d. push-me, pull-me yolk | SCRd | SC5 |

C.4.3.2 <u>Insertion and Removal of Shield Boxes and Graphite Cavity (Continued)</u>

| | Ident. Symbol | Storage |
|---|---|---|
| .2.3 Graphite Blocks (GB) and Cylinders (GC) | | |
| a. block with cavity | GB1 | |
| b. block with 8" dia. penetration | GB2 | |
| c. 8" dia. cyl. for GB1 w/2.74" penetration | GC1 | |
| d. 8" dia. cyl. for GB2 " " | GC2 | |
| e. 8" dia. cyl. assembly for ISNF | GC3 | SC2 |
| f. yolk for opening GB1 | GBa | LT3 |
| g. T-bar for pushing GB1,2 | GBb | SC5 |
| h. attachment rod for removing graphite blocks | GRc | LT3 |
| i. wishbone for ISNF cyl. ass'y. GC3 | GRd | |
| j. rod and wishbone attachment for cylinders GC1&2 | GRe | LT3 |

C.4.3.3 <u>Roll-Away Lift Table (LT)</u>

| | Ident. Symbol | Storage |
|---|---|---|
| .3.1 Tools, Storage, and Th.Col. Attachments | | |
| a. wrench for lift sprocket | LTa | LT3 |
| b. box wrench and Th.Col. stud nuts & washers | LTb | LT1 |
| c. shelves: top(LT1), middle(LT2), lower(LT3) | LT1-3 | |
| .3.2 Peripherals | | |
| a. body shield attached to roll-away table | BS | |
| b. glass brick & mounting wedges for body shield | GLB | HS3 |
| c. portable lead shield (access dia.=1.62") | PSa | HS3 |
| w/extension | | HS2 |
| d. dolly for portable shield | PSb | HS3 |
| and guide | | HS2 |
| e. front bracket ass'y. for portable shield (2 pieces, 2 atchmnt screws) | PSc | HS2 |
| f. Boron-loaded polythene blocks (100 or so on roll table | | |

C.4.3.4 <u>Heavy Duty Yellow Roll Table (RT)</u>

| | Ident. Symbol | Storage |
|---|---|---|
| .4.1 Peripherals | | |
| a. riser platform to match level of lift table | RTa | |

C.4.3.5 <u>Shield Cave (SC)</u>

| | Ident. Symbol | Storage |
|---|---|---|
| .5.1 storage shelves (5): SC1(top)...SC5(bottom) | SC1-5 | |
| .5.2 inner shielded enclosure and roll door | SCa | |
| .5.3 roll-away cave shield door | SCb | |
| w/start-roll lever (stored in roof channel) | SCb1 | |

C.4.3.6 STORAGE SITES FOR HARDWARE (HS)

Summary:

>Top shelf of lift table (LT1)

>Middle shelf of lift table (LT2)
---tools and hardware for removal and insertion of middle and outer shield boxes (SB2, SB3);
---reduction cylinders for inner box penetration

>Lower shelf of the lift table (LT3)
---all penetration plugs
---tools and major hardware for removal and insertion of inner shield box (SB1) and graphite cavity (GB, GC) [larger tools are also in shield cave, lower shelf (HS3/sc5)]

| Specific Sites: | Symbol |
|---|---|
| >Lift table shelves [LT1(top), LT2(middle), LT3(bottom] | LT1-3 |
| >Shield cave shelves [SC1(top)--SC5(bottom] | SC1-5 |
| >Lucite boxes marked "Th.Col.Assy." at lift table [store on LT1] | HS1 |
| >Drawer marked CAVITY FISSION SOURCE / ISNF in 4-drawer wheeled cartHS2 | HS2 |
| >Table at wall near Th.Col. curtain control | HS3 |

C.4.4 Photographs

C.4.4.1 Index
["o" indicates no photo]

----------------------------------------------

**SI: Source Insertion Tube Assembly**

SIa source insertion tube
o [source tabs and stop ring, 1.635"o.d.]

SIa1 stop ring for source insertion tube

SIb1,2 source mounting tabs
[upper and lower source tabs protruding from portable shield
with detector capsule inserted]

SIc1,2 twist lock rings (2) w/spacer disks
o[lock rings and spacers for cinching source disk into source tab]

CV5-10 source disks [pair of U235 metal source disks wrapped in aluminum foil]

----------------------------------------------------------------

**CI: Detector Capsule Insertion Assembly**

CIa insertion guide for detector capsule push rod
[capsule insertion assembly with push rod withdrawn]

CIb push rod w/ stop, detector capsule holder & cap
[push rod extended; from top: capsule holder, detector capsule (CC), holder cap;
left: capsule cap removal tool (SITa)]
[procedure for using SITa to remove (press-fit) capsule holder cap]

oCIc push rod extension

----------------------------------------------------------------

**SI/CI: Peripherals**

oLC lead cup & cap for source disk storage

SITa tool for removing capsule-holder cap

SITb detector capsule dummy

SITc twist wrench for source disk assembly and removal

SITd pull hook for SI

CC cadmium capsules (3 scribed A, B, C)

Cd lucite detector-capsule carrier

**SB: Thermal Column Shield Boxes**

SB1 Lead shield box (inner)
[12"x12"x10-5/8" w/inner cylinder]

SB1a. 8" dia. cylinder plug w/2.690" dia. penetration

SB1b. penetration reduction tube w/ screw
(1.870" dia.x14"long)

SB1c. lead shield plug and handle (1.81" dia.)

SB1d. guide tube & stop for CFS insertion
w/ screw (1.635" i.d.)

oSB1e. shield bar

oSB1f. platform with guides and end stop, side bars

oSB1g. cinch pins (2) for box and cylinder

SB1h. steel shield plug & handle (1.63" dia.)

SB1i. lead shield plug & handle (2.7" dia.)

SB1j. steel shield plug for SB1b

----------------------

SB2 Shield Box (outer)
[15"x15"x9" w/ cylinder]

SB2a. cylinder (8.7" o.d.) w/1.83" dia. penetration

SB2b. lead closure plug (1.77"dia.)

SB2c. clamp for outer shield box

----------------------

SB3 Shield box (middle)
[15"x15"x7-3/4" w/2.748" dia. penetration]

SB3A. lead closure plug w/ 0.825" dia. penetration

SB3b. steel plug for lead closure plug

SB3c. lucite neutron shield (12.5"x11.25"x4" detachable)

**SBR/SCR: Insertion and Removal Hardware**

SBRa pull rods for shield boxes (3)
SBRb removable platform with roller guides
oSBRc lead bricks (2) & spacer block
SBRd push tube & bar for inner shield box
SBRe lift table track -- right
  f. " " " -- right back
  g. " " " -- left front
  h. " " " -- left back
SBRi pulley assembly and pull cord

SCRa inner runway for inner cylinder, SB1a
SCRb outer runway w/stop, risers(2), and cinch pins(2)
SCRc cradle with rollers
SCRd push-me, pull-me yolk

---

**GB/GC/GR: Graphite Blocks and Cylinders**

oGB1 block with cavity
oGB2 block with 8" dia. penetration
GBa yolk for opening GB1
GBb T-bar for pushing GBl,2

oGC1 8" dia. cyl. for GBl w/2.74" penetration
oGC2 8" dia. cyl. for GB2 " "
oGC3 8" dia. cyl. assembly for ISNF

GRc attachment rod for removing graphite blocks
GRd wishbone for ISNF cyl. ass'y. GC3
GRe rod and wishbone attachment for cylinders GC1&2

---

**LT: Roll-Away Lift Table**

LTa wrench for lift sprocket
LTb box wrench and Th.Col. stud nuts & washers
oLT1-3 shelves: top(LT1), middle(LT2), lower(LT3)

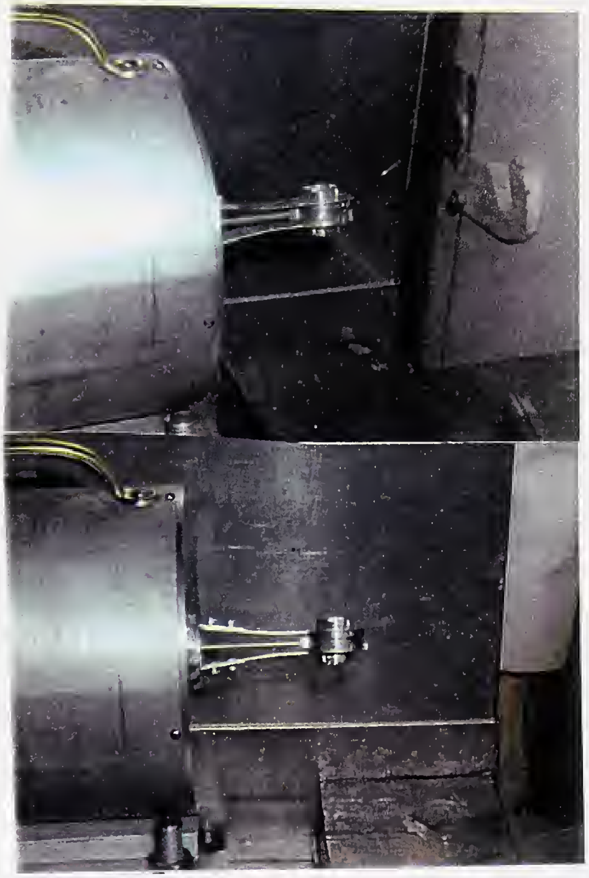
---

**LT: Peripherals**

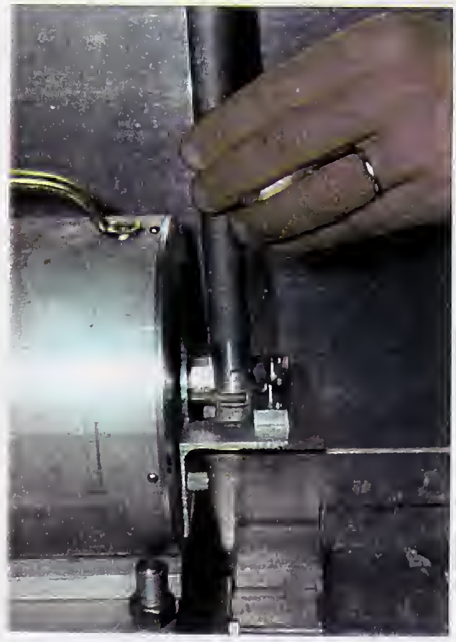
BS body shield attached to roll-away table
GLB glass brick & mounting wedges for body shield
PSa portable lead shield w/ext. piece
PSb dolly for portable shield and guide plate
PSc front bracket ass'y. for portable shield
  (2 pieces, 2 attachmnt screws)

## C.4.4.2 Photographs

SI Source Insertion Tube Assembly



SIb1,2 source mounting tabs
[upper and lower source tabs protruding from portable shield with detector capsule inserted]



SIc1,2 twist lock rings (2) w/spacer disks
[source assembly with twist lock wrench SITc]

CV5-10 source disks
[pair of U235 metal source disks wrapped in aluminum foil]

SIa1 stop ring for source insertion tube

C.4.4.2 Hardware Photos

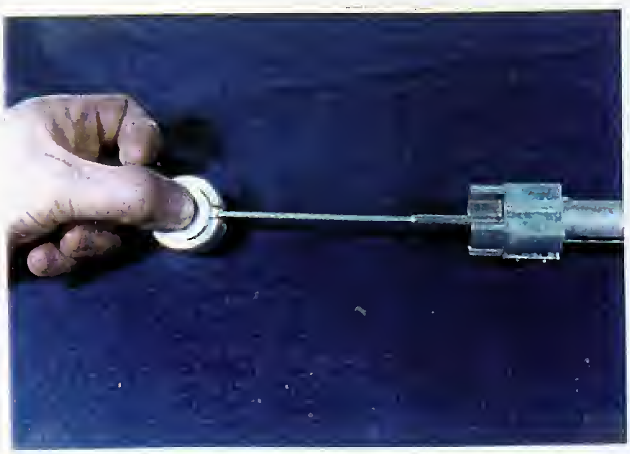
CI Detector Capsule Insertion Assembly

CI Detector capsule insertion assembly
[inserting CI into source insertion assembly SI]

CIb Push rod
[CI inserted into SI, endview showing end stop, clamp, and attachment screw]

CIa Insertion guide for detector capsule push rod
[capsule insertion assembly with push rod withdrawn]

CIb Detector capsule holder assembly
[capsule holder, detector capsule (CC), holder cap; left: cap removal tool (SITa)]



CIb Push rod
[procedure for using tool SITa to remove press-fit capsule holder cap]

CIb Push rod
[extended w/ detector capsule holder & cap]

C.4.4.2 Hardware Photos

SI/CI PERIPHERALS

CC Cadmium capsules (3 scribed A, B, C)

CC Cadmium capsule with "hat" for detector foil assembly

Cd Lucite carrrier and cap for detector capsule
SITb Detector capsule dummy [normally in detector sule holder to allow holder cap removal with SITa]

SITa Removal tool for capsule-holder cap

SITc Wrench for source disk assembly and removal

C.4.4.2 Hardware Photos

SB THERMAL COLUMN SHIELD BOXES

SB2/SB2a: Outer shield box w/ 8.7"dia. cylinder

SB3: Middle shield box w/ lead closure plug, SB3a, and steel plug, SB3b

SB2b: Lead closure plug

SB3b: Steel plug for SB3a

SB2c: Clamp for outer shield box

SB3c: Lucite neutron shield for SB2

SB1j: Steel shield plug for reduction tube, SB1b

C.4.4.2 Hardware Photos

SB THERMAL COLUMN SHIELD BOXES

SB1/SB1a/SB1b/SB1g: Inner lead shield box complete with 8"dia. cyl. (SB1a), penetration reduction tube w/attchmnt screw (SB1b), eyebolt for pull cord, cinch pin (SB1g)

SB1: Inner lead shield box w/ CFS guide tube (SB1d) in place

SB1i: Lead shield plug (2.7"dia.) for SB1a

SB1d: CFS Guide tube and stop

SB1c: Lead shield plug (1.81"dia.) for penetration reduction tube (SB1b) w/o handle extension

SB1h: Steel shield plug for CFS guide tube, SB1d

C.4.4.2 Hardware Photos

SBR/SCR INSERTION AND REMOVAL HARDWARE
FOR SHIELD BOXES

SBRa: Pull rods for shield boxes

SBRd: Push tube & bar for inner cylinder, SB1a

SBRb: Platform w/ roller guides

SBRb: Platform detail showing lift table lock

SBRe,f,g,h: Lift Table tracks for SB1 box withdrawal

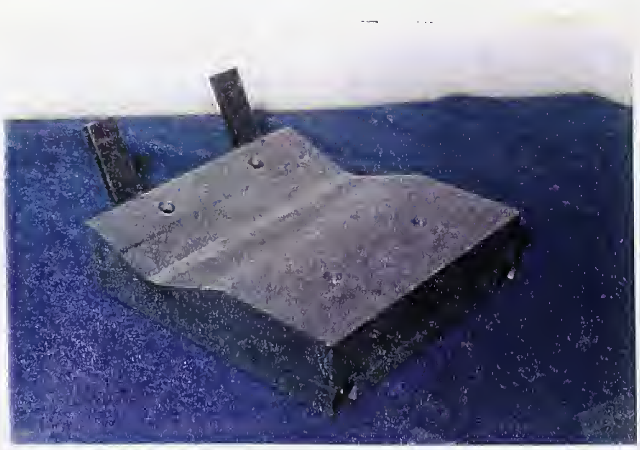
C.4.4.2 Hardware Photos

SBR/SCR INSERTION AND REMOVAL HARDWARE
FOR SHIELD BOXES

SCRb: Outer runway on lift table

SCRa: Inner runway for inner cylinder, SB1a

SCRd: Push-me, pull-me yolk



SCRc: Cylinder cradle with rollers

SBRi: Pulley assembly and pull cord

C.4.4.2 Hardware Photos

GB/GC: GRAPHITE BLOCKS & CYLINDERS

GRc: Attachment rod for removing blocks, GB1,2

GRd: Wishbone for ISNF cylinder assembly, GC3

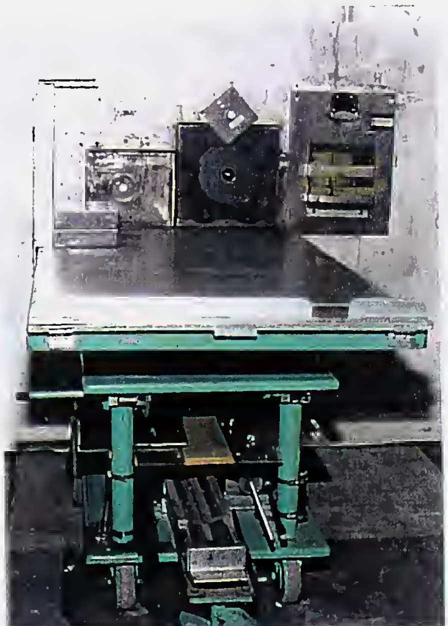
GBa: Yolk for opening cavity block, GB1

GBb: T-bar for pushing GB1,2

GRe: Rod and wishbone attchmnt. for removing cylinder GC1,2

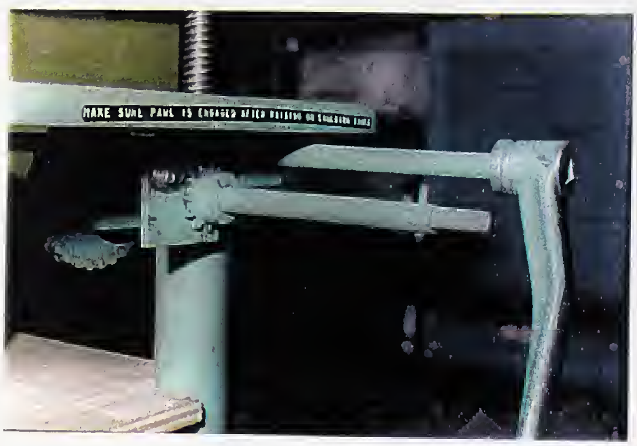
C.4.4.2 Hardware Photos

LT/PS: ROLL-AWAY LIFT TABLE AND PERIPHERALS



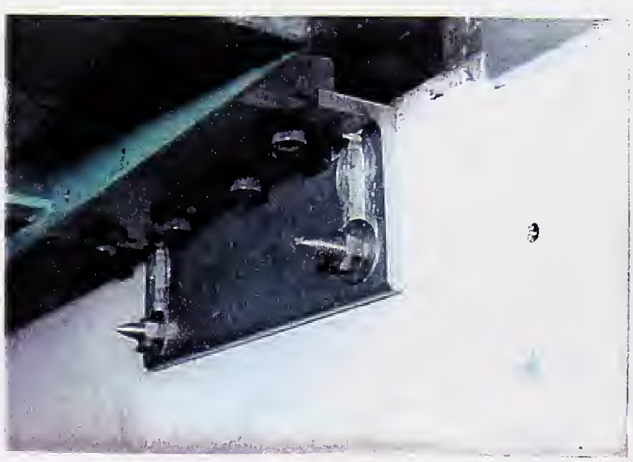
LT: Roll-away lift table at th.col.
w/storage shelves (LT.1,2,3)


BS: Body shield attached to lift table
w/glass brick in place for viewing



LT: Lift sprocket with hand set locking pawl

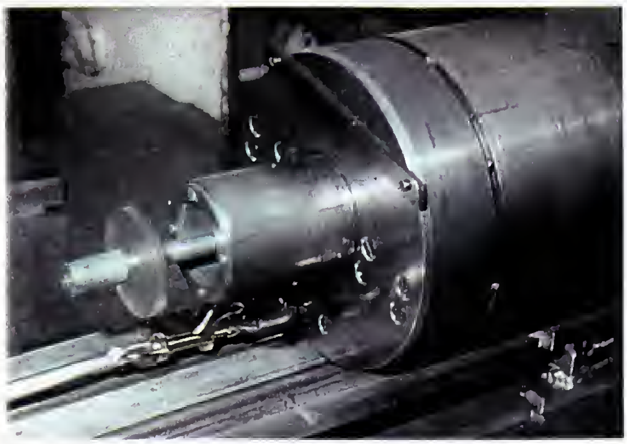
LTa: Wrench for lift sprocket

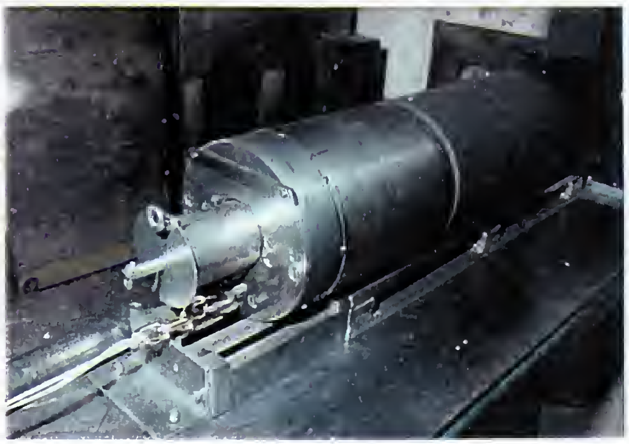


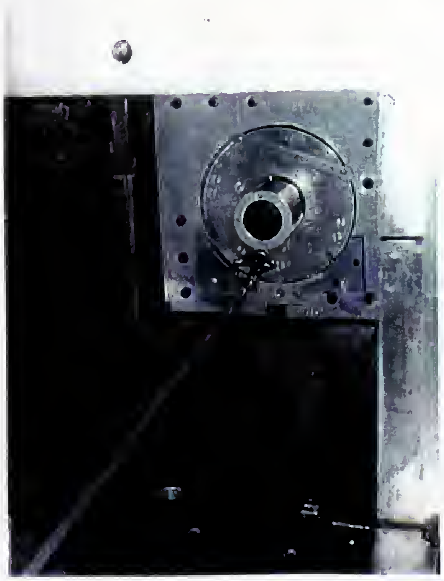
LT: Lift table attachment at thermal column

C.4.4.2 Hardware Photos

REMOVAL OF INNER CYLINDER (SB1a)
AND SHIELD BOXES

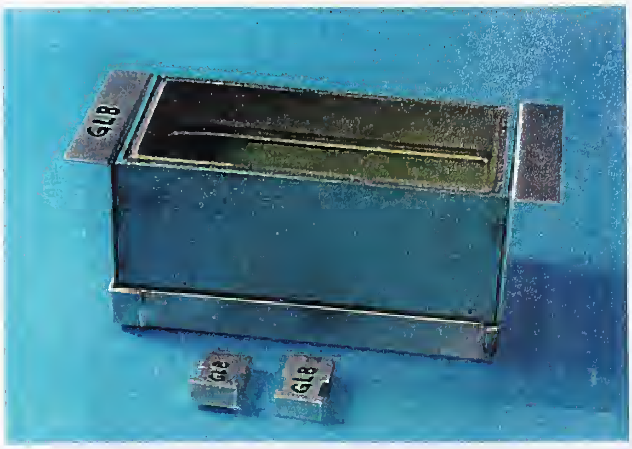






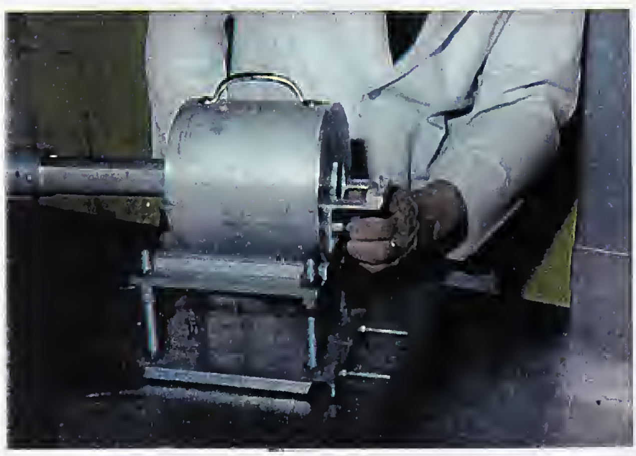
C.4.4.2 Hardware Photos

LT/PS: ROLL-AWAY LIFT TABLE AND PERIPHERALS




GLB: Glass brick and mounting wedges

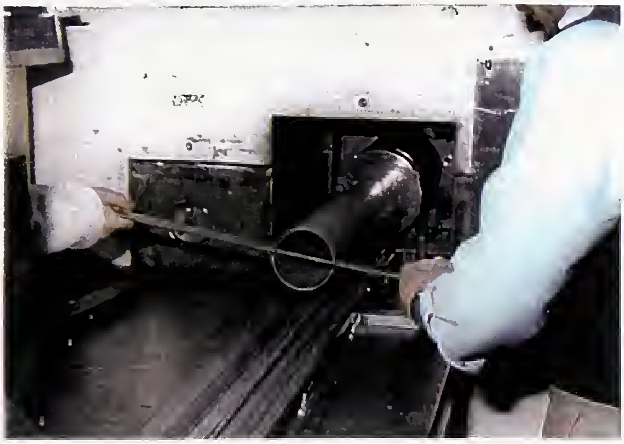
PSa: Portable lead shield w/ extension piece,
PSB: Dolly for portable shield



PSC: Front bracket assembly.

C.4.4.2 Hardware Photos

INSERTION OF INNER CYLINDER (SB1a)
AND SHIELD BOX



# D. FORMS AND CODES

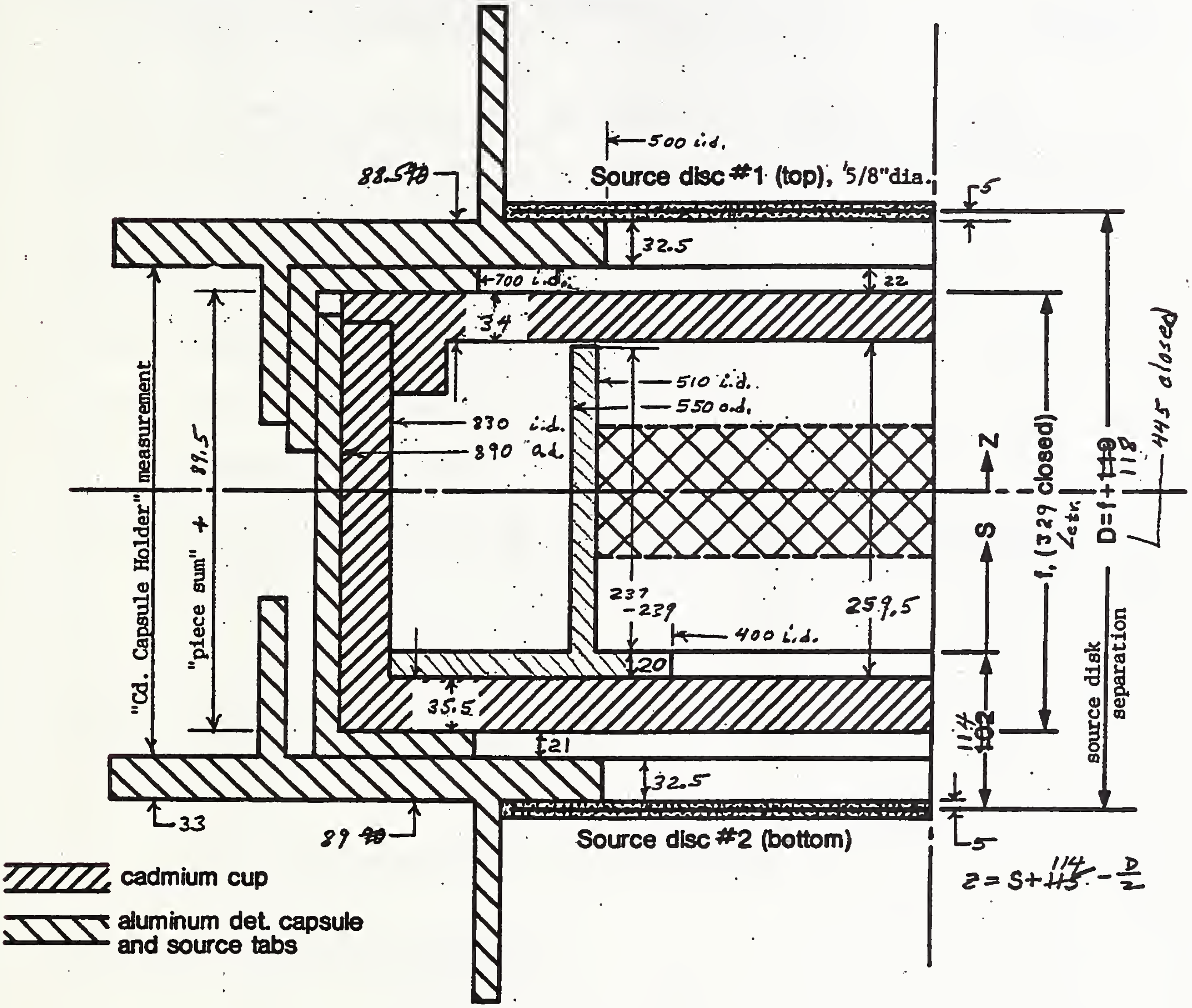
D.1 Source Detector Assembly
- 1.1 Half-Section drawings and detector assembly worksheet
- 1.2 Axial fluence gradient
- 1.3 Irradiation record and preliminary information sheet

D.2 Fission Neutron Fluence Determination
- 2.1 FLUDER: qpro spreadsheet for derivation of neutron fluence
- 2.2 SATFAC: activation decay correction
- 2.3 SCATCOR: code for scattering corrections: capsule, foils, and cavity return
- 2.4 STPBG: code for counting lab operation
  [reference only, not in this documentation]

D.3. Test Report Forms

## D.1 SOURCE DETECTOR ASSEMBLY

### D.1.1. HALF-SECTION DRAWING OF SOURCE DETECTOR ASSEMBLY
[Figure B.1-2 from Section B.1.2 / dimensions in mils]




Cadmium Capsule "C" (all dimensions in mils)

D = fission source disk separation distance (midplane is at D/2)

S = distance from bottom of detector assembly "hat" to the center of the foil.

Z = position of detector center relative to the midplane between the sources
(Z is zero at midplane and positive for positions above midplane,
i.e. towards upper source disk)
= S - 112 (nominal for capsule C)

[Measurement details are in notations for the Detector Assembly Worksheet.]

## D.1.1 DETECTOR ASSEMBLY WORKSHEET FOR CAVITY FISSION SOURCE

fac/cfsoper,p.66

Assembly date: Irradiation i.d. EOI:

| [1]Assembly Piece | | Depth Measurement to Foil Surface (mils) | | S assigned | Z see note (2) (D = ) |
|---|---|---|---|---|---|
| i.d. | thk. (mils) | piece sum | micro-meter | (mils) | |
| | | bottom | 237 | | |

Assembled Cd. capsule ( ): f = ; capsule holder:

---

S = distance from foil center to bottom of detector assembly hat
Z = position of foil center measured from midplane between sources

[over]

D.1.1 Detector Assembly Worksheet For Cavity Fission Source

NOTATIONS FOR DETECTOR ASSEMBLY WORKSHEET
[position parameters defined in Fig.B.1-2] fac/cfsoper

(1) Pieces are assembled with i.d. number up. All dimensions are in mils

(2) Error does not include uncertainty in midplane position. Position uncertainty for the monitor is relative to the adjacent foil.

----------------------------------------------

S = distance from bottom of detector assembly hat to the center of the foil.

= 237 - ["Depth Measurement"] - [1/2 foil thickness]

f = dimension of assembled cadmium capsule "C"

D = source disk separation: f + 118

Z = position in mils of the detector center relative to the midplane between the sources.
(Z=0 at midplane; Z is positive for positions above midplane, i.e. towards upper source disk)

= S + 114 - D/2 = S - f/2 + 56

----------------------------------------------

Example: capsule "C" closed (f=333 and D=451):

Z = S - 112

= 126 - ["Depth Measurement"] - [1/2 foil thickness]

------------------------------

Assembled capsule holder: 370 (nominal)

D.1.2 AXIAL NEUTRON FLUENCE GRADIENT
[Fig.B1-1 in Section B.1.2]

Axial fluence gradient from Ref.82-4. The minimum fluence for the least-squares fit is at S = 120mils, the midplane between the fission source disks.

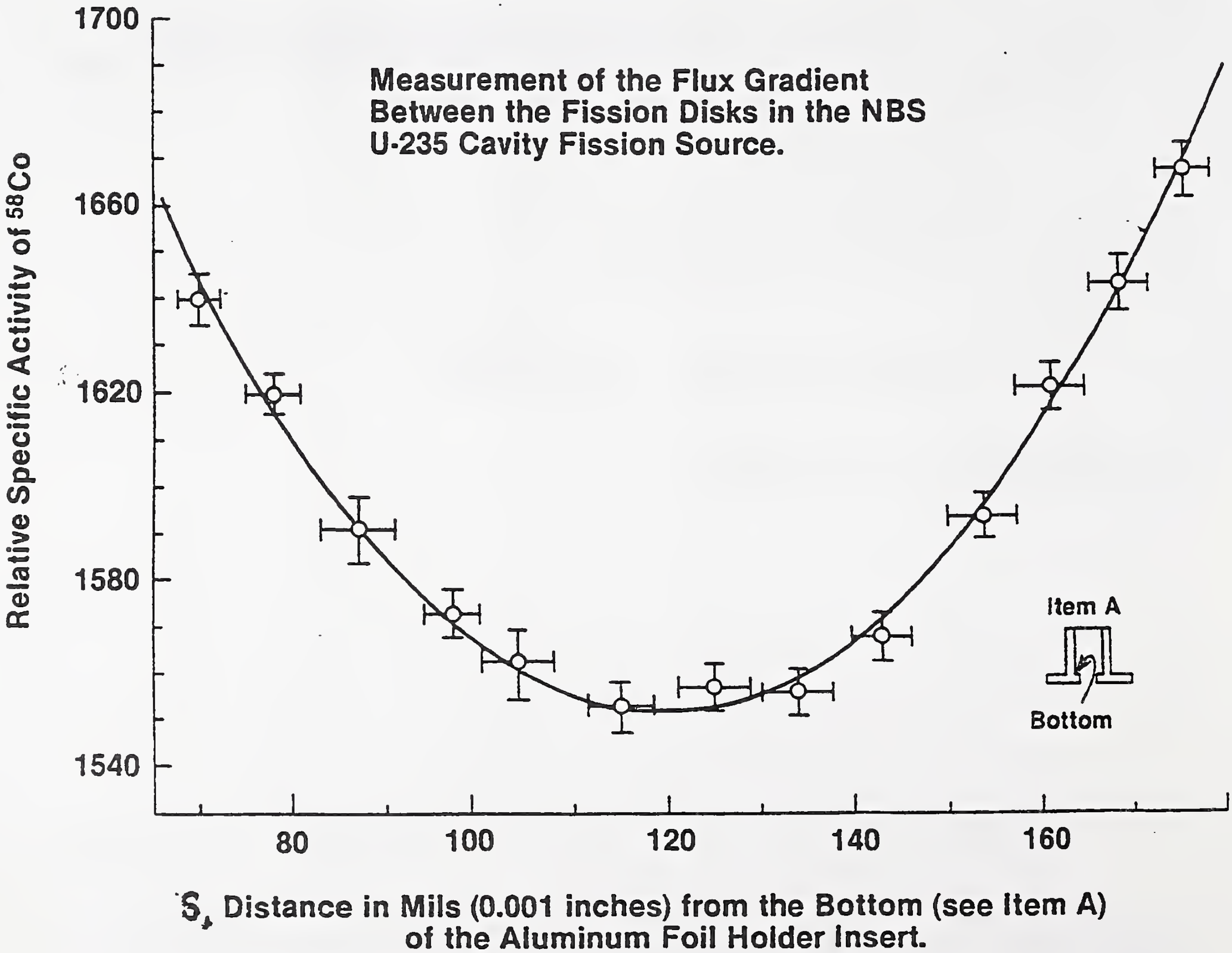
The fluence relative to unity at the midplane is given by,

$$\Phi = 1.347 - 5.81E\text{-}3\ S + 2.429E\text{-}5\ S^2 = 1 + 2.43E\text{-}5\ Z^2$$

The distances S and Z are defined in Fig.B1-2. Example: for S = 160mils (Z=40), $\Phi$ = 1.039.

Note: The gradient parabola in the present version of FLUDER, based on more recent measurements, differs somewhat from Ref.82-4:

$$\Phi = 1 + 2.12E\text{-}05\ Z^2$$



D.1.3 Irradiation Record And Preliminary Information Sheet

IRRADIATION RECORD

1. Irradiation i.d:

   Exposure: megawatt x hours = MW-hr

2. Nominal Neutron Fluence at Z = 0:

3. Materials Irradiated and Capsule Position:

   i.d:

   Z:

4. <u>Source Assembly</u> i.d. R/h @ 10cm, time

   Top Source Disk CV-

   Bottom Source Disk CV-

   Source separation distance: D = f + 118mils =

   Detector capsule facing tab SIB___

5. <u>Irradiation Interval</u>

   SOI (start boral curtain up):

   Date: Time: EST

   EOI (start boral curtain down):

   Date: Time: EST

   [Length of irradiation: T = EOI - SOI = ]

Irradiation Operator: ______________________ Date: ___________

Checked by: ______________________ Date: ___________

PRELIMINARY INFORMATION FOR CAVITY FISSION SOURCE IRRADIATION
(Test Report to follow)

1. Irradiation i.d.

Requestor/User:

2. End-Of-Irradiation (EOI): Date: Time: (EST)

Length of irradiation:

3. Materials Irradiated

i.d:

Time History
Correction, C:

Nominal
Neutron Fluence:

Calculated
Cross Section:
(ENDFB-VI dosimetry file)

4. Contact:

# D.2. FISSION NEUTRON FLUENCE DETERMINATION

D.2. Fission Neutron Fluence Determination

2.1 FLUDER: qpro spread sheet for deriving neutron fluence and fluence rate

2.2 SATFAC: activation decay correction

2.3 SCATCOR: code for scattering corrections: capsule, foils, and cavity return

2.4 STP2D8: code for counting lab operations [reference only, not in this document]

**D.2. Fission Neutron Fluence Determination**

D.2.1 FLUDER: QPRO SPREAD SHEET FOR DERIVATION OF FISSION NEUTRON FLUENCE AND FLUENCE RATE

>Set up in QPRO by E. D. McGarry
--supplementary information in manilla folders:
"CFS: Operations Manual" and "CFS: Calculations"
--precursor LOTUS-1987 is obsolete

>Operational description is in Section B.2

>Sample spread sheet with annotation
--WP5.1 file: C:\cfscodes\fluder\FLDRM97.WQ1
--QPRO file: C:\qpro\fluder\FLDRM97.WQ1

>Working spread sheet for new irradiations
--redo title; overwrite and delete appropriate input quantities
[do not close up blank rows]
--WP5.1 file: C:\cfscodes\fluder\fldrwrk.wq1
--QPRO file: C:\qpro\fluder\fldrwrk.wq1

## D.2.1 SAMPLE QPRO SPREAD SHEET FOR FLUDER WITH COLUMN DESIGNATIONS
[File: c:\qpro\fluder\fldrm97.wq1]

SAMPLE FLUDER SPREAD SHEET FOR CFS OPERATIONS MANUAL, SECTION D.2.1
[PC file: C:\qpro\fldrm97.wq1 and C:\cfscodes\fldrm97.wq1

CAVITY FISSION SOURCE IRRADIATION 12-Mar-97
[irradiation i.d. / qpro file]

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I.D. | POS. | T(mils) | Mu(abs) | RATE(c/s) | MASS(g) | Rate/M | 1-e^-Mu*T | C(del r) | CORR. RT. | GRADIENT | MU SCAT | D CORRED |
| Ni-BT | -58.0 | 10.0 | 0.0015 | 1162.0 | 0.2810 | 4135.2 | 0.9925 | 1.0000 | 4166.3 | 1.071 | -0.0097 | 3927 |
| Ni-M | -29.0 | 10.0 | 0.0015 | 1115.0 | 0.2828 | 3942.6 | 0.9925 | 1.0000 | 3972.2 | 1.018 | -0.0095 | 3940 |
| Ni-U | 11.5 | 3.5 | 0.0015 | 308.9 | 0.0793 | 3894.7 | 0.9974 | 0.9974 | 3894.8 | 1.003 | -0.0111 | 3927 |
| Ni-N | 50.0 | 10.0 | 0.0015 | 1142.5 | 0.2824 | 4045.7 | 0.9925 | 1.0000 | 4076.1 | 1.053 | -0.0091 | 3906 |
| Ni-AK | 85.5 | 10.0 | 0.0015 | 1249.0 | 0.2814 | 4438.5 | 0.9925 | 1.0000 | 4471.9 | 1.155 | -0.0106 | 3913 |
| | | | | | | | | | | | AVERAGE= | 3923 |
| | | | | | | | | | | | STD.DEV.= | 12 |
| | | | | | | | | | | | %STD.DEV.= | 0.2998 |

| A' | B' | K' | N | O |
|---|---|---|---|---|
| | | | DETECTOR FREE-FIELD | |
| I.D. | POS. | GRADIENT | FLUENCE | FLUENCE RATE |
| Ni-BT | -58.0 | 1.0713 | 7.227E+15 | 2.82E+10 |
| Fe-H | -48.0 | 1.0488 | 7.075E+15 | 2.76E+10 |
| Ni-M | -29.0 | 1.0178 | 6.866E+15 | 2.68E+10 |
| Ti-BJ | -9.0 | 1.0017 | 6.757E+15 | 2.64E+10 |
| Ni-U | 11.5 | 1.0028 | 6.765E+15 | 2.64E+10 |
| Cu-AU | 30.5 | 1.0197 | 6.879E+15 | 2.68E+10 |
| Ni-N | 50.0 | 1.0530 | 7.103E+15 | 2.77E+10 |
| Fe-S | 68.0 | 1.0980 | 7.407E+15 | 2.89E+10 |
| Ni-AK | 85.5 | 1.1550 | 7.791E+15 | 3.04E+10 |

| P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|
| K fact | DUMMY | T 1/2(d) | t(sec) | LAMB.(1/s) | SATFAC | G |
| 1.920E+05 | 1.0000 | 70.82 | 256200 | 1.1328E-07 | 0.02861 | 1.117E-07 |

| W | X |
|---|---|
| FREE FIELD MIDPLANE FLUENCE | FREE FIELD MIDPLANE FLUENCE RATE |
| 6.746E+15 | 2.633E+10 |

| A'' | O' | Y | Z |
|---|---|---|---|
| I.D. | FLUENCE RATE | SIGMA (mb) | PHI*SIGMA |
| Ni-BT | 2.82E+10 | 105.00 | 2.963E-15 |
| Fe-H | 2.76E+10 | 81.00 | 2.238E-15 |
| Ni-M | 2.68E+10 | 105.00 | 2.815E-15 |
| Ti-BJ | 2.64E+10 | 11.20 | 2.955E-16 |
| Ni-U | 2.64E+10 | 105.00 | 2.773E-15 |
| Cu-AU | 2.69E+10 | 0.55 | 1.477E-17 |
| Ni-N | 2.77E+10 | 105.00 | 2.912E-15 |
| Fe-S | 2.89E+10 | 81.00 | 2.343E-15 |
| Ni-AK | 3.04E+10 | 105.00 | 3.194E-15 |

D.2.1 ANNOTATION OF FLUDER QPRO SPREAD SHEET -- 05March97

[Underlined labels indicate input information. * From Detector Assembly Worksheet]

| Col. | Label | Explanation |
|---|---|---|
| **Ni Monitor Response** | | |
| A. | I.D. | *Ni foil monitor identification |
| B. | POS. | *Ni foil position measured from midplane<br>(Z in mils from Detector Assembly Worksheet) |
| C. | T(mils) | *thickness of monitor foil in mils |
| D. | MU(abs) | $\gamma$ absorption factor |
| E. | RATE(c/s) | Ni monitor response from ctg lab (c/s at EOI)<br>(corrected for pulse losses and backgrounds) |
| F. | MASS(g) | Ni monitor foil mass (gm) |
| G. | Rate/M | Ni monitor response in c/s per gm<br>(col.E) / (col.F) |
| H. | (1-e^-Mu*T) | $\gamma$ absorption correction<br>[1 - exp(-(col.C)(col.D))] / [(col.C)(col.D)] |
| I. | C(del r) | shelf correction for foil thickness<br>1 + (0.008)[(col.C) - 10)]/2 |
| J. | CORR.RT. | corrected monitor response (c/s per gm)<br>(col.G)(col.I) / (col.H) |
| K | GRADIENT | neutron fluence relative to midplane<br>1 + (2.12E-5)$(col.B)^2$ |
| L. | MU SCAT | neutron scattering correction entered from SCATCORR Code<br>[Includes cavity return / see Sect.D.2.3] |
| M. | D C0RRED | monitor response (c/s per gm) corrected to midplane (z=0)<br>and for neutron scattering (free-field value):<br>(col.J) / [(col.K)(1 + col.L)] |

Average value and std. dev. are given below individual values in Col.M: "AVERAGE=" / "std.dev.=" / "%std.dev.="

D.2.1 ANNOTATION OF FLUDER QPRO SPREAD SHEET -- Continued [05March97]

| Col. | Label | Explanation |
|---|---|---|

**Free-Field Neutron Fluence at midplane (Z=0)**

| Col. | Label | Explanation |
|---|---|---|
| P | K fact | K-factor (Ni fluence calibration factor from ctg. lab) |
| Q | DUMMY | not used [note: set=1; wall-return in SCATCORR] |
| R | T 1/2(d) | Ni monitor half-life in days |
| S | t(sec) | length of irradiation in seconds |
| T | LAMB.(1/s) | Ni monitor decay constant:<br>$\lambda$(Co58) = ln2 / (70.824)(3600) = 1.133E-7 |
| U | SATFAC | activation decay correction:<br>[1 - exp(-$\lambda$T)] or entered from SATFAC code.<br>$\lambda$ from Col.T; T from Col.S [see Sect.D.2.2] |
| V | G | activation decay rate factor<br>G = (SATFAC)/T = (col.U) / (col.S) |
| W | FLUENCE | free-field neutron fluence at midplane<br>$\Phi$(z=0) = [k-factor] [D-corred avg.] / G<br>= (col.P) ["AVERAGE=" in (col.M)] / (col.V) |
| X | FLUENCE RATE | free-field neutron fluence rate at midplane<br>$\phi$(z=0) = (col.W) / (col.S) |

**Free-Field Neutron Fluence at Detector Position**

| Col. | Label | Explanation |
|---|---|---|
| A' | I.D. | *detector identification |
| B' | POS. | *detector position measured from midplane (mils)<br>(Z in mils from Detector Assembly Worksheet) |
| K' | GRADIENT | fluence at detector relative to midplane<br>$1 + (2.12E-5)(col.B')^2$ |
| N | FLUENCE | free-field neutron fluence at detector ($n/cm^2$)<br>(col.W)(col.K') |
| O | FLUENCE RATE | free-field neutron fluence rate at detector ($n/cm^2,s$)<br>(col.N)/(col.S) |

| Col. | Label | Explanation |
|---|---|---|

Free-Field Reaction Probability

| Col. | Label | Explanation |
|---|---|---|
| A" | I.D. | detector identification (col.A') |
| O' | FLUENCE RATE | free-field neutron fluence rate at detector (col.O) |
| Y | SIGMA | reaction cross section in mb [SOURCE NOT GIVEN] |
| Z | PHI*SIGMA | average reaction rate $\sigma\phi$ = (col.X)(col.O') |

## D.2.1 WORKING FLUDER SPREAD SHEET FOR NEW IRRADIATIONS
[File: C:\qpro\fluder\fldrwrk.wq1]

WORKING FLUDER SPREAD SHEET
[Retitle, delete and overwrite for a new irradiation]
[PC file: C:\qpro\fluder\fldrwrk.wq1 and C:\cfscodes\fluder\fldrwrk.wq1

CAVITY FISSION SOURCE IRRADIATION 31-Mar-97
[irradiation i.d. / qpro file]

| A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I.D. | POS. | T(mils) | Mu(abs) | RATE(c/s) | MASS(g) | Rate/M | 1-e^-Mu*T | C(del r) | CORR. RT. | GRADIENT | MU SCAT | D CORRED |
| Ni-BT | -58.0 | 1.0 | 0.0015 | 1000.0 | 1.0000 | 1000.0 | 0.9993 | 0.9964 | 997.1 | 1.071 | -0.0097 | 940 |
| Ni-M | -29.0 | 1.0 | 0.0015 | 1000.0 | 1.0000 | 1000.0 | 0.9993 | 0.9964 | 997.1 | 1.018 | -0.0095 | 989 |
| Ni-U | 12.0 | 1.0 | 0.0015 | 1000.0 | 1.0000 | 1000.0 | 0.9993 | 0.9964 | 997.1 | 1.003 | -0.0111 | 1005 |
| Ni-N | 50.0 | 1.0 | 0.0015 | 1000.0 | 1.0000 | 1000.0 | 0.9993 | 0.9964 | 997.1 | 1.053 | -0.0091 | 956 |
| Ni-AK | 86.0 | 1.0 | 0.0015 | 1000.0 | 1.0000 | 1000.0 | 0.9993 | 0.9964 | 997.1 | 1.157 | -0.0106 | 871 |
| | | | | | | | | | | | AVERAGE= | 952 |
| | | | | | | | | | | | STD.DEV.= | 47 |
| | | | | | | | | | | | %STD.DEV.= | 4.9019 |

| A' | B' | K' | N | O | P | Q | R | S | T | U | V |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DETECTOR FREE-FIELD | | | | | | | | |
| I.D. | POS. | GRADIENT | FLUENCE | FLUENCE RATE | K fact | DUMMY | T 1/2(d) | t(sec) | LAMB.(1/s) | SATFAC | G |
| Ni-BT | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | 1.920E+05 | 1.0000 | 70.82 | 10 | 1.1328E-07 | 0.00000 | 1.133E-07 |
| Fe-H | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Ni-M | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Ti-BJ | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Ni-U | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Cu-AU | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Ni-N | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Fe-S | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |
| Ni-AK | 1.0 | 1.0000 | 1.614E+15 | 1.61E+14 | | | | | | | |

| W | X |
|---|---|
| FREE FIELD MIDPLANE | |
| FLUENCE | FLUENCE RATE |
| 1.614E+15 | 1.614E+14 |

| A'' | O' | Y | Z |
|---|---|---|---|
| I.D. | FLUENCE RATE | SIGMA (mb) | PHI*SIGMA |
| Ni-BT | 1.61E+15 | 105.00 | 1.695E-10 |
| Fe-H | 1.61E+15 | 81.00 | 1.307E-10 |
| Ni-M | 1.61E+15 | 105.00 | 1.695E-10 |
| Ti-BJ | 1.61E+15 | 11.20 | 1.808E-11 |
| Ni-U | 1.61E+15 | 105.00 | 1.695E-10 |
| Cu-AU | 1.61E+15 | 0.55 | 8.877E-13 |
| Ni-N | 1.61E+15 | 105.00 | 1.695E-10 |
| Fe-S | 1.61E+15 | 81.00 | 1.307E-10 |
| Ni-AK | 1.61E+15 | 105.00 | 1.695E-10 |

### D.2.2 SATFAC: ACTIVATION DECAY CORRECTION

>The activation decay correction, SATFAC in col.U of FLUDER, for an uninterrupted irradiation of length T at constant fluence rate is,

$$\text{SATFAC} = [1 - \exp(-\lambda T)],$$

where $\lambda$ is the activation decay constant from Col.T, and T is the length of irradiation from Col.S. The activation decay rate factor G in col.V is obtained directly,

$$G(\lambda,T) = (\text{SATFAC}) / T$$

>When the irradiation time history is more complicated, a QPRO spread sheet SATFAC can be used to generate the activation decay correction for FLUDER. A sample output of this spread sheet for detectors with half-lives of 71 and 39 days irradiated for 27 days with a 5 day interruption is shown on the following page.

>A normalized activation decay rate factor, $C = G/\lambda = (\text{SATFAC}) / \lambda T$, is given in Test Reports. The quantity C is close to unity when the half-life of the detector reaction is long compared to the length of irradiation and hence indicates the sensitivity of the detector response to the accuracy of irradiation time history and the half-life of the activation.

>In cases of serious variation of reactor power level, an irradiation time-history monitor may be required when $C = G/\lambda$ is not close to unity. A fission chamber has been used for this purpose, and in fact, has been successfully coupled to an HP-85 data acquisition computer to generate SATFAC directly.

D.2.2 Sample Outputs of QPRO spread sheet for SATFAC

[27 day irradiation with a 5 day interruption / detector half-lives: 71 and 39 days]

QPRO
SPREADSHEET: SATFAC01.WQ1

Activity at End of an Irradiation (EOI) With Non-Constant Power

Eq. 1=(1-exp(-Lamda*Ti))   Eq. 2= exp(-Lamda*Tj)

| Ti | Pi | | Pi*Ti | Tj | Eq. 1 | Eq. 2 | P*Eq-1 | A(Ti) | A(Ti) SATFA |
|---|---|---|---|---|---|---|---|---|---|
| 16.5 | 1.0000 | 16.5 | 16.537 | 10.9 | 0.1493 | 0.8991 | 0.1493 | 0.1343 | 0.71 |
| 5.4 | 0.0000 | 21.9 | 0.000 | 5.5 | 0.0512 | 0.9476 | 0.0000 | 0.0000 | 0.00 |
| 5.5 | 1.0000 | 27.4 | 5.499 | 0.0 | 0.0524 | 1.0000 | 0.0524 | 0.0524 | 0.28 |
| | | | | | 0.25289 | | 0.2017 | | |
| Tot Tim | 27.4 | | 0.804 | | | | | | |

HafLife 70.870
Lamda 9.78E-03
Time in Days

Saturation Factor: A(EOI) = 0.1866
Average Power = 0.8040
Ave. Power Normalized SATFAC = 0.2321
[1-exp(-Lamda*T)] = 0.2351
Ratio of SATFAC to the above = 0.7937

QPRO
SPREADSHEET: SATFAC02.WQ1

Activity at End of an Irradiation (EOI) With Non-Constant Power

Eq. 1=(1-exp(-Lamda*Ti))   Eq. 2= exp(-Lamda*Tj)

| Ti | Pi | | Pi*Ti | Tj | Eq. 1 | Eq. 2 | P*Eq-1 | A(Ti) | A(Ti) SATFA |
|---|---|---|---|---|---|---|---|---|---|
| 16.5 | 1.0000 | 16.5 | 16.537 | 10.9 | 0.2523 | 0.8260 | 0.2523 | 0.2084 | 0.69 |
| 5.4 | 0.0000 | 21.9 | 0.000 | 5.5 | 0.0901 | 0.9079 | 0.0000 | 0.0000 | 0.00 |
| 5.5 | 1.0000 | 27.4 | 5.499 | 0.0 | 0.0921 | 1.0000 | 0.0921 | 0.0921 | 0.30 |
| | | | | | 0.43452 | | 0.34441 | | |
| Tot Tim | 27.4 | | 0.804 | | | | | | |

HafLife 39.430
Lamda 1.76E-02
Time in Days

Saturation Factor: A(EOI) = 0.3005
Average Power = 0.8040
Ave. Power Normalized SATFAC = 0.3738
[1-exp(-Lamda*T)] = 0.3823
Ratio of SATFAC to the above = 0.7860

## D.2.3 SCATCORR CODE FOR SCATTERING CORRECTIONS [February96]

The SCATCORR code written in BASIC(QB45) provides a total scattering correction for the source detector capsule, other foils, foil self-scatter, and cavity return. The result is given as the fractional change in response for five classes of detectors.

### GENERAL NOTES

1. Outline
   >Written & compiled in BASIC (QB45) by E.D. McGarry (revised Feb96)
      --location: C:\CFSCODES\SCATCORR
      --information in folders: "CFS -- Operations Manual" and "CFS Calculation"
      --SCATFO is obsolete
   >Output: "MU-SCAT"
      [Total Measured Activity] = [Free-Field Activity] [1 + (MU-SCAT)]
   >Elements of Code
      --program (ASKII): SCATCORR.BAS
      --BASIC code operation: SCATCORR.EXE
      --output file: SCATCORR.DAT
   >Discussion and References: CFS/Fac.Char. document, Sect. B.2

2. Operation
   >start: call up SCATCORR.EXE; escape: CTRL^C
   >1st prompt: enter number of detectors
   >2nd prompt: enter w/ upper case and comma between:
      --foil i.d: alpha/num
      --choose foil type by number
         (1<K<5): (1)Np237, (2)U238/In115, (3)Ni58/Fe54, (4)Ti46, (5)Al27/Cu63
      --foil position in foil stack relative to midplane (in mils)
      --foil thickness in mils
   >ENTER runs program
   >output file: SCATCORR.DAT
      --overwrites; contains only the last run
      --print in DOS: COPY SCATOUT.DAT LPT1: [form feed]

3. Algorithm

>all results are fractional change in response of detector k

>gradient in foil stack: GRAD = $[1 + 2.12E\text{-}5(\text{foil pos.})^2]$

>foil-to-foil scattering

--based on curve fit to curves in Fig.EDM-SC1 data from CE memo 25July90; see last section of folder "CFS: Calculations"

--SCAT(I,K) = Sum(J): Thkns(J) x [a(K) + b(K)xexp(-c(K)xpos(J,I))] where a, b, and c are parameters of fit for 1<K<5 foil types given in Fig.EDM-SC1

--SCAT(I,K) output is fractional change in response of Ith detector

>self-scatter: [b(K) - a(K)] x thknss(I)

--[b - a] are the zero intercepts in Fig.EDM-SC1, but see also CE memo 30Nov95

>capsule scatter (Ref: "CFS: Calculations" folder, MCNP section, CE memo 30Nov95)

>cavity return (Ref: "CFS: Calculations" folder, ANISN section, #4 on Summary Sheet)

(reference information is in #4 below and in folder "CFS: Oper. Man.")

>Total scattering: MU-SCAT = SCAT + (self-scatter) + (capsule scatter) + (cavity return)

4. Summary memo updating SCATCORR parameters

Date: 28November95

To: E.D.McGarry
From: Jim Grundl
Subject: New capsule scattering and cavity return parameters for SCATCORR

1. Clerical error in parameter "d" entry for Np: 0.15 should be 0.015

2. New values for parameter "d" in SCATCORR from Nov95 Monte Carlo calculations of capsule scattering including cadmium box, fission source disks, aluminum capsule and inner detector holder ("hat"). [Ref. CE memo 27Nov95]

| | | | | | |
|---|---|---|---|---|---|
| k: | 1 | 2 | 3 | 4 | 5 |
| det: | Np | U238/In | Ni58/Fe54 | Ti46 | Al$\alpha$/Cu63$\alpha$ |
| d: | 0.014 | 0.00 | 0.000 | -0.004 | -0.006 |

3. Values for cavity return to be entered as a new parameter. Taken from 1-D ANISN calculations of the CFS cavity by CEisenhauer (Sept94) and a CFS midplane fluence value of 0.117 from Nov95 Monte Carlo calculations.

| | | | | | |
|---|---|---|---|---|---|
| k: | 1 | 2 | 3 | 4 | 5 |
| det: | Np | U238/In | Ni58/Fe54 | Ti46 | Al$\alpha$/Cu63$\alpha$ |
| cvyret: | 0.004 | 0.002 | 0.001 | 0.000 | 0.000 |

## D.2.3 ANNOTATION OF SCATCORR OUTPUT (SCATCORR.DAT) [February96]

[Underlined labels indicate input information]

"BASIC PROGRAM 'SCATCORR' CALCULATIONS"
[see D.2.3 General Notes, #3]

| Col. | Label | Explanation |
|---|---|---|
| A | I.D. | detector foil identification |
| B | TYPE | choice of foil type<br>(Np237, U238/In115, Ni58, Fe54, Ti46, Al27/Cu63) |
| C | POS. | foil position relative to the midplane in mils (0.001") |
| D | GRADIENT | neutron fluence relative to the midplane |
| E | THKNESS | foil thickness in mils (0.001") |
| F | SCAT | fractional change in response of foil indicated in col.A<br>due to scattering from other foils |
| G | MU-SCAT | total scattering correction: MU-SCAT = col.F + [self-scatter] +<br>[col.d: capsule scatter] + [col.f: cavity return] |

"LIBRARY OF CONSTANTS USED IN THE ABOVE CALCUATIONS"
[No labels for this section / see D.2.3 General Notes, #3]

| | |
|---|---|
| k | index of 5 foil types represented in SCATCORR<br>k=1(Np); k=2(U238/In115); k=3(Ni58/Fe54); k=4(Ti46); k=5[Al/Cu63(n,$\alpha$)] |
| a,b,c | parameters of curve fitting for 1<k<5 foil types |
| d | fractional change in k-type detector for capsule scattering |
| e | fractional change for self-scattering |
| f | fractional change for cavity return |

SAMPLE OUTPUT OF SCATCORR (FEB96)

```
"       BASIC PROGRAM  'SCATCORR'  CALCULATIONS                    "
 A          B            C       D            E         F          G
"I.D.      TYPE         POS.    GRADIENT     THKNESS   SCAT       MU-SCAT    "
NI-BT      3            -58     1.07132       10       0.00000    0.00000
U8-1       2            -48     1.04884       10       0.00000    0.00000
IN-1       2            -29     1.01783       10       0.00000    0.00000
TI-BJ      4             -9     1.00172       20       0.00000    0.00000
NI-U       3             12     1.00305        4       0.00000    0.00000
CU-A       5             31     1.02037       25       0.00000    0.00000
AL-1       5             61     1.07889       10       0.00000    0.00000
NP-1       1             71     1.10687       10       0.00000    0.00000
FE-S       3             81     1.13909       10       0.00000    0.00000
NI-AK      3             91     1.17556       10       0.00000    0.00000

"       LIBRARY OF CONSTANTS USED IN THE ABOVE CALCULATIONS     "
K    a          b          c          d          e=b-a      f
1 0.00090    0.00660    0.06000    0.01400    0.00570    0.00400 — Np
2 0.00120    0.00610    0.07280    0.00500    0.00490    0.00200 — U238/In
3 0.00175    0.00355    0.09400    0.00000    0.00180    0.00100 — Ni/Fe54
4 0.00200    0.00330    0.09800   -0.00400    0.00130    0.00000 — Ti46
5 0.00340    0.00260    0.03500   -0.00600   -0.00080    0.00000 — Al27/Cu63
```

SCREEN AFTER ENTER TO RUN

```
 *** Input MUST be in Capital Letters ***

INPUT FOR EACH FOIL IN THE STACK:
FOIL I.D., TYPE (i.e. U238), POSITION (IN MILS), THICHNESS (MILS)
NI-BT, 3, -58, 10
U8-1,  2, -48, 10
IN-1,  2, -29, 10
  OUTPUT IS ON FILE = SCATOUT.DAT

STOP in module SCATCORR at address 2B19:08AE

Hit any key to return to system
```

## D.3 TEST REPORT FORMS

## D.3. TEST REPORT FORMS

Preliminary Report Of Test

NEUTRON FLUENCE CALIBRATION AT THE NIST $^{235}$U CAVITY FISSION NEUTRON SOURCE

Irradiation ID: Report Date:

Sensor Materials Irradiated:

(designations:

End of Irradiation (EOI):

REPORT FOR:

Free field, fission-neutron fluence (averaged over volume of the detectors):

$\Phi =$ n/cm$^2$

Physical description:

Form: mm dia. × mm thk disk

Material:

Additional parameters of irradiation:

Decay correction factor: C = using $\lambda$ =

Length of irradiation: T =

Departure from free-field activity due to neutron scattering:

$\mu_{sc} =$

Radial gradients of the neutron fluence are substantial: center-to-edge ratio is about 1.25 for 12 mm diameter sensor disks.

Other Radioactivities:

Since the sensors are natural metal samples, activities from neutron reactions in other isotopes and impurities may be present. Ordinarily, this will not be a problem for Ge(Li) and other high resolution gamma detectors. The following lines have been observed above the annihilation energy:

Reference Documents:

(1) G. P. Lamaze and J. A. Grundl, "Activation Foil Irradiation with Californium Fission Source," NBS SP-250.13, U.S. Department of Commerce (March 1988).

(2) "Compendium of Benchmark Neutron Fields for Reactor Dosimetry," NIST Document NBSIR-3151 (January 1986).

This fluence standard prepared by:

______________________________

Neutron Dosimetry Group

Reviewed by:

______________________________

D. M. Gilliam
Neutron Interactions and Dosimetry Group

For the Director

______________________________

B. M. Coursey
Ionizing Radiation Division

File copy only

Data on spreadsheet:

| laboratory | contact | Irr. Sensors sent | Test Report sent |
| --- | --- | --- | --- |

D.3 Final Test Report

## NEUTRON FLUENCE RATE CALIBRATION AT THE NIST $^{235}$U CAVITY FISSION NEUTRON SOURCE

Irradiation ID: Report Date:

Sensor Materials Irradiated:

(designations:

End of Irradiation (EOI):

REPORT FOR:

Free field, fission-neutron fluence rate (averaged over volume of the detectors):

$<\phi> =$ $n/(cm^2\ s)$

Physical description:

Form: mm dia. × mm thk disk

Material:

Additional parameters of irradiation:

Decay correction factor: $[\lambda TC] =$ using $\lambda =$

Length of irradiation: T =

Departure from free-field activity due to neutron scattering:

$\mu_{sc} =$

Radial gradients of the neutron fluence are substantial: center-to-edge ratio is about 1.25 for 12 mm diameter sensor disks.

Other Radioactivities:

Since the sensors are natural metal samples, activities from neutron reactions in other isotopes and impurities may be present. Ordinarily, this will not be a problem for Ge(Li) and other high resolution gamma detectors. The following lines have been observed above the annihilation energy:

Inventory of Uncertainties For Calibration of the CFS Via the Pu239(n,f) Reaction ($\pm 1\sigma$)*

[Revised October, 1987]

[After 1990: items 3 & 4 replaced by a single value of ±1.5%; new total uncertainty is ±2.5% -- see CFS/Fac.Char. document, Section B.3.2]

o Neutron Fluence Transfer From the $^{252}Cf$ Standard Fission Neutron Field to the $^{235}U$ Cavity Fission Source:

| | |
|---|---|
| (1) Absolute neutron source strength of the $^{252}Cf$ source | 1.1% S+R |
| (2) Distance measurement | 0.2% R |
| (3) $^{252}Cf$-to-$^{235}U$ spectrum-averaged cross section ratio for Pu(n,f) transfer reaction | 0.1% S |
| (4) Neutron scattering correction for Pu(n,f) transfer reaction | 0.9% S |
| (5) Reproducibility of fluence transfer procedure (including counting statistics and electronic system stability over period of measurement) | 0.4% |
| (6) Neutron scattering correction in Ni fluence transfer monitor | 1.4% S |
| | ---------- |
| Quadrature sum: | 2.1% |

o Neutron Fluence Calibration at the $^{235}U$ Cavity Fission Source

| | |
|---|---|
| (1) Gradient corrections and positioning | 0.4% S+R |
| (2) Neutron scattering corrections for $^{58}Ni(n,p)$ | 0.8% S |
| (3) Reproducibility of fluence monitoring including random summing corrections and uncertainties in activation decay corrections | 0.3% R |
| | ------------ |
| Quadrature sum: | 0.9% |
| | -------------------- |
| Total Uncertainty: | ±2.3% (±4.6% expanded) |

*S is for systematic uncertainty and R is for random uncertainty.

Relationship of Test Report Data to the Measured Sensor Activity at End of Irradiation (EOI) for Cavity Fission Neutron Source Irradiations

The neutron fluence or fluence rate standard has been exposed to a fission neutron fluence that is perturbed by a small cavity return flux and by the effects of neutron scattering in fission source disks, source-sensor assembly, and the neutron sensors themselves. This test report certifies a free-field fission neutron fluence or fluence rate (i.e., corrected for neutron scattering) averaged over the volume of the sensor. This correction, based on calculation, is given as the fractional departure from the free-field sensor response attributable to neutron scattering including cavity return. On this basis the sensor activity measured at EOI is

$$A_m = A\,(1 + \mu_{sc}) \tag{1}$$

where: $A_m$ = sensor activity measured at EOI

$A$ = net free-field activity at EOI

$\mu_{sc}$ = fractional departure from free-field activity due to neutron scattering. (A minus sign means that the observed activity is lower than it would be in free-field conditions because of a net outscatter of neutrons.)

Activation equation for neutron fluence. For simple radioactive decay, the unperturbed activity of the neutron sensor in disintegrations per second at EOI is related to the free-field fission neutron fluence by the activation equation:

$$\frac{A}{\lambda\ C\ N} = \sigma \cdot \phi \tag{2}$$

where: $A$ = net free-field sensor activity at EOI (dps) from eq (1)

$\lambda$ = decay constant of the reaction product ($s^{-1}$)

$C$ = decay correction factor given in test report. For an uninterrupted irradiation of length T at a constant fluence rate, C is equal to $[(1-\exp(-\lambda T))/\lambda T]$. (When it is appropriate to report average neutron fluence rate, the decay correction factor is given as the product $\lambda TC$ – see below.)

$N$ = number of reaction isotope atoms in the sensor

$\sigma$ = fission-spectrum-averaged reaction cross section ($cm^2$)

$\Phi$ = free-field fission neutron fluence ($n/cm^2$) given in this test report.

$[\sigma \cdot \Phi]$ = reaction probability

Activation equation for average neutron fluence rate. For decay half-lives short compared to the length of irradiation, the activation equation is commonly expressed in terms of the average reaction rate (experimentally, the saturated specific activity):

$$\frac{A}{[\lambda TC]\, N} = \sigma \cdot \langle \varphi \rangle \tag{3}$$

$\frac{A}{[\lambda TC]N}$ = saturated specific activity

$[\lambda TC]$ = decay correction factor for average neutron fluence rate. For an uninterrupted irradiation of length T at constant fluence rate, $[\lambda TC]$ is equal to $[1-\exp(-\lambda T)]$.

T = length of irradiation given in the test report.

$\sigma$ = fission-spectrum-averaged reaction cross section ($cm^2$)

$\langle\phi\rangle$ = average, free-field, fission neutron fluence rate ($n/cm^2\ s$) given in this test report.

$\sigma\cdot\langle\phi\rangle$ = average reaction rate ($s^{-1}$)

Activation equation for fission product activity. When the observed gamma disintegration is from the direct formation of a fission product, Equation 2 becomes

$$A = Y \cdot \lambda \cdot C \cdot N \cdot (\sigma \cdot \Phi)\ , \tag{4}$$

where Y is the chain fission yield. When the fission product actvity is from the daughter of a radioactive parent with a half life longer than that of the daughter, the appropriate free-field activity at equilibrium is

$$A = [\lambda'/(\lambda'-\lambda)] \cdot Y \cdot \lambda \cdot C \cdot N \cdot (\sigma \cdot \Phi) \tag{5}$$

where $\lambda$ is the decay constant of the parent activity and $\lambda'$ that of the daughter.

Recommended Procedure for Establishing a Calibration Factor ($\chi_{25}$)

Use eqs (2) through (5) as appropriate to derive a free-field neutron fluence or average fluence rate from the measurement of a particular activity of the neutron sensor. Define a calibration factor for this activity as the ratio of the NIST certified fission neutron fluence or fluence rate to the derived neutron fluence or fluence rate. Then, to obtain an NIST calibrated result for subsequent measurements with this sensor, either multiply observed reaction probabilities by the calibration factor or divide the spectrum-averaged cross section by the calibration factor.

In general, this calibration will be most effective if a calculated fission-spectrum-averaged cross section is used in eqs. (1) through (5). In particular, it should be obtained with the same fission spectrum shape and energy dependent reaction cross section as are used to establish a spectrum-averaged cross section for subsequent neutron field measurements (e.g. from a neutron transport calculation). For the NIST-evaluated and ENDF/BV fission spectrum shapes and a reaction cross section from the ENDF/B-V Dosimetry File, calculated fission-spectrum-averaged cross sections for the __________ reaction are _______ mb for NIST-evaluated and __________ mb for ENDF/BV. Other calculated fission-spectrum-averaged cross sections can be furnished on request.

Revised: June 11, 1989

# E. REFERENCES

E.0. Standard Neutron Fields Documentation (1998)

E.1. NIST Documentation -- CFS
- 1.1 Archive reports and unpublished documents
- 1.2 NIST Publications (1970 thru 1993)

E.2. Other Documentation -- CFS
- 2.1 Other publications
- 2.2 Reference list from Compendium of Benchmark Neutron Fields For Reactor Dosimetry (NBSIR 85-3151, 1986)

E.3. Files
- 3.1 Diskettes (WP5.1)
- 3.2 Manilla folders

**E.0. STANDARD NEUTRON FIELDS DOCUMENTATION (1998)**

NIST Internal Reports: NISTIR 6419, 6420, 6421, 6422, 6423
>WP5.1 files: Diskettes, Directory NISTIR

Source: NIST contract documents listed in Sect. E.3.1
>WP5.1 files: Eight Diskettes, Directory docsnf
>File Index in docsnf/snffiles and docsnf/snfdoc
>Archive (hard copy): eight binders, photo album, manilla folders

PRIMARY DOCUMENTATION

0.1 NIST CAVITY FISSION SOURCE [CFS] -- OPERATIONS MANUAL
[NISTIR 6419]
[WP5.1 files: NISTIR/RCFSOPER.JNO, */RCFSOPER.REF, */RCFSOPER.HID]

0.2 NIST CAVITY FISSION SOURCE [CFS] -- FACILITY CHARACTERISTICS
[NISTIR 6420]
[WP5.1 files: NISTIR/RCFSCHAB, */RCFSCHC, */RCFSCHD, */RCFSCHE]

0.3 NIST MATERIALS DOSIMETRY REFERENCE FACILITY [MDRF]
--OPERATIONS MANUAL
[NISTIR 6422]
[WP5.1 files: NISTIR/RMDRFOPR]

0.4 NIST MATERIALS DOSIMETRY REFERENCE FACILITY [MDRF]
--FACILITY CHARACTERISTICS
[NISTIR 6423]
[WP5.1 files: NISTIR/RMDRFABD, */RMDRFC]

0.5 NIST CALIFORNIUM FISSION NEUTRON IRRADIATION FACILITY [CNIF]
[NISTIR 6421]
[WP5.1 files: NISTIR/RCNIFMAD, */RCNIFME]

0.6 ARCHIVE PUBLICATIONS FOR NEUTRON INTERACTIONS AND DOSIMETRY GROUP [1970 -- 1993]
[two binders, WP5.1 file: NISTIR/RREFPUB]

E.0. STANDARD NEUTRON FIELDS DOCUMENTATION

INDEX OF REFERENCE SECTIONS IN PRIMARY DOCUMENTATION WITH HARD COPY LOCATION

**E.1. NIST DOCUMENTATION -- CFS**

E.1.1 Archive Reports And Unpublished Documents

1.1-1 "Formulations For Neutron Field Characterization Measurements With Integral Detectors" (J. Grundl, 31July96)
[locations: this document and others in this series;
WP5.1 file: C:\wp51\docsnf\formulas.ju6]

1.1-2 Status of Neutron Fluence Calibrations for NIST Standard Neutron Fields (Memo from E. D. McGarry, J. A. Grundl, 01Oct96)
[locations: this document and others in this series;
WP5.1 file: C:\fac\flucal]

1.1-3 Memos Describing Scattering Calculations (including *.e and *.rr Files) (C. M. Eisenhauer, 11July96 and earlier)
[Manilla Folder: "CE(97) Compendium of Scattering Calculations"]

1.1-10. DETAN95: Computer Code for Calculating Spectrum-Averaged Cross Sections and Detector Responses in Neutron Spectra; NISTIR 5622 (C.M. Eisenhauer, Dec. 95)
[Manilla Folder: "Eisenhauer Doc. >95"]

1.1-11. "Directory and Explanation of CRAY Files Generated by the DETAN Computer Code" (C. M. Eisenhauer, 08December95)
[Manilla Folder: "Eisenhauer Doc. >95"]

1.1-12. DETAN96: Documentation Of Interactive Code For WP5.1
(C. M.Eisenhauer, June96) [Manilla Folder: "Eisenhauer Doc. >95"]

1.1-13. Assumptions And Models In Neutron Transport Codes Used To Calculate Neutron Spectra in NIST Standard Neutron Fields (C. M. Eisenhauer, 25Feb98)
[WP51: docsnf/stndfld.ce] [Manilla Folder: "Eisenhauer Doc. >95"]

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82-6. Grundl, J. A., Eisenhauer, C. M., and McGarry, E. D., "Neutron Flux Measurements in the Pressure Vessel Cavity of an Operating U.S. Power Reactor," LWR Pressure Vessel Irradiation Surveillance Dosimetry Progress Report, HEDL-Time 8218, NUREG/CR-2805 Vol.I, (March, 1982).
[location: CFS--Fac.Char., Sect.E.1.1, separate publications binder]

Separate Bound Documents

88-4. Activation Foil Iradiation by Reactor Cavity Fission Sources, G. Lamaze, J. Grundl, NBS Special Publication 250-14, National Institute of Standards and Technology, (March, 1988)

86-1. Compendium of Benchmark Neutron Fields for Reactor Dosimetry, J. Grundl, C. M. Eisenhauer, NBSIR 85-5131, National Institute of Standards and Technology (January 1986).

REFERENCE E.1.1-1

FORMULATIONS FOR NEUTRON FIELD CHARACTERIZATION MEASUREMENTS WITH INTEGRAL DETECTORS
[August 1996]

**Sections:**

1. Generic Formulations
2. Calibration Factor
3. Activation Detector Measurements
4. Fission Chamber Measurements
5. Other Parameters
6. Sample Inventory of Uncertainties for Neutron Fluence Measurements With Activation Detectors

**References:**

1. Compendium of Benchmark Neutron Fields for Reactor Dosimetry, NBSIR 85-3151, Part IA, Section 5.
2. NIST Test Report: "Neutron Fluence Calibration at the NIST $^{235}$U Cavity Fission Source" [see NIST CFS Operations Manual, Section D.3]
3. "Neutron Fluence Measurement in the Pressure Vessel Cavity of an Operating U.S. Power Reactor," LWR Pressure Vessel Irradiation Surveillance Dosimetry Progress Report, NUREG/CR-2805, Vol. I, 1982. [hard copy: Ref.82-6 in Section E.1.1 of NIST CFS Facilities Characteristics Document]
4. NIST Document: NIST Cavity Fission Source--Facility Characteristics, Section C.1.
5. "Neutron Fluence Monitoring of MDRF Irradiations With $Ni^{58}$(n,p) Activation Detectors," NIST Document: MDRF--Facility Characteristics, Section D.2.3

### 1. Generic Formulation

The reaction probability (disintegrations per nucleus) is the product of the spectrum-averaged, reaction cross section and the neutron fluence, $\sigma \cdot \Phi$; similarly, the average reaction rate (disintegrations per second per nucleus) is the product of the reaction cross section and the average neutron fluence rate, $\sigma \cdot \langle \phi \rangle$:

$$R = \sigma \cdot \Phi \tag{1a}$$

$$\frac{R}{T} = \sigma \cdot \langle \phi \rangle \tag{1b}$$

where T is the length of irradiation. The reaction probability is sometimes referred to as the total reactions per target nucleus or the time-integrated reaction rate.

As a measured quantity, the reaction probability may be written as,

$$R = \frac{\mu D}{\epsilon G N} \tag{2a}$$

and the average reaction rate,

$$\frac{R}{T} = \frac{\mu D}{\epsilon (GT) N} \tag{2b}$$

R = reaction probability (dis/nucl.)

D = observed detector response ($s^{-1}$)

N = number of detector isotope atoms
[(mass of detector isotope x Avogadro's No.) / (isotopic mass)

$\epsilon$ = detection efficiency
[The reciprocal of the detection efficiency factor in Ref. 1.)

$\mu$ = residual detector response factor
[Composite of detector response factors, exclusive of [$\epsilon$, G, N] and not included in D, required to connect the observed detector response to reaction probability or to reaction rate. Examples are neutron field perturbations; correction for competing reactions; effective fraction of detector atoms including neutron self absorption; fission yield; branching ratio; and extrapolation of pulse height distribution, background subtraction, and pulse losses.]

T = length of irradiation

$G(\lambda,T)$ = activation decay rate factor for activation detector response, D, at end-of-irradiation (EOI). It is sometimes called the saturation factor or the time history correction when the time profile of the irradiation is complicated. This separation of the time history correction is only possible when the neutron spectrum does not change during the irradiation. For simple radioactive decay, and an uninterrupted irradiation of length T at constant fluence rate, $G = [1-\exp(-\lambda T)]/T$. For an irradiation with interruptions of zero fluence, $TG = \sum_i [\exp(-\lambda t_{di})]\,[1-\exp(-\lambda(t_{ui}-t_{di}))]$, where $T = \sum_i (t_{ui}-t_{di})$ for up and down times $t_{ui}$ and $t_{di}$ measured from EOI. The dimensionless quantity $C = G/\lambda$ is also used in order to facilitate uncertainty estimates by indicating how much the activation decay correction departs from $\lambda T$. $G(\lambda,t)$ for simple decay and an arbitrary irradiation time history, $\phi(t)$, is given by,

$$G(\lambda,t) = \frac{\lambda \int_{-T}^{0} \phi(t)\, e^{\lambda t}\, dt}{\int_{-T}^{0} \phi(t)\, dt} \quad ,$$

where T is the total length of irradiation, and $\lambda$ is the decay constant.

For detectors that directly measure reaction probability (e.g. SSTR's) or reaction rate (e.g. fission chambers), G = 1 or 1/T, respectively.

A neutron fluence (or fluence rate) is obtained by dividing the reaction probability (or average reaction rate) by the spectrum-averaged cross section.

The ratio of spectrum average cross sections for detector pairs with distinguishable energy response ranges is called a spectral index. As such it is the basic quantity for neutron spectrum diagnostics with integral detectors. According to Eq.1, a measured spectral index is the ratio of reaction probabilities or average reaction rates:

$$S_{\alpha/\beta} = \frac{\sigma_\alpha}{\sigma_\beta} = \frac{R_\alpha}{R_\beta} = \frac{(R/T)_\alpha}{(R/T)_\beta} \quad . \tag{3}$$

## 2. Calibration Factor

Neutron field characterization measurements often employ fission spectrum calibration. A calibration factor based on a fission neutron irradiation is defined in NIST Test Reports as the certified fission neutron fluence, $\Phi_\chi$, divided by the neutron fluence, $\Phi$, determined with the detector irradiated. Using Eqs.1a and 2a,

$$K \equiv \frac{\Phi_\chi}{\Phi} = \Phi_\chi \cdot \left[\frac{D}{(\sigma_\chi)_{calc}}\,\frac{\mu}{\epsilon N G}\right]^{-1} \tag{4}$$

$(\sigma_\chi)_{calc}$ = $^{235}U$ fission-spectrum-averaged cross section calculated with the same fission neutron source spectrum used in the transport calculation for the study field

The detector irradiated is commonly called a neutron fluence standard in the case of activation detector measurements. When appropriate, the calibration factor for a specific detector and detection scheme can be used in place of the detection efficiency.

### 3. Activation Detector Measurements

The natural outcome of activation detector measurements is the neutron fluence obtained by dividing the reaction probability of Eq.2a by the cross section averaged over the spectrum in which the detector was exposed. The average reaction rate of Eq.2b, when divided by the same cross section, gives the neutron fluence rate.

Individual counting lab procedures will generally provide as dps/nucleus:

specific activity at EOI: $\mu D/\epsilon N$,

saturated specific activity: $R/T = \mu D/\epsilon(GT)N$ (Eq.2b)

Ordinarily, the composite response factor, $\mu$, will be incomplete (e.g. counting labs do not usually include neutron field perturbations). The incorporation of corrections into D or into $\mu$ is a matter of individual laboratory preference. When $\mu$ is complete, the saturated specific activity for simple radioactive decay is equal to the average reaction rate.

Alternatively, or in addition, the counting lab may provide the following: the detector count rate, D, at EOI, generally with some corrections applied; the saturated count rate per gram for the detector element, $\mu D/GTM$; the net free-field sensor activity at EOI, $\mu D/\epsilon$, as discussed in NIST Test Reports (Section C.2); or the fission-equivalent neutron fluence described in Section 5.a.

When fission spectrum calibration is employed, optional calibration factors may be obtained from a neutron fluence standard depending on whether or not the absolute detection efficiency is used. They are derived as follows. Write Eq.(2a) for a detector irradiated in the neutron field under study and for the neutron fluence standard, both counted with the same detection efficiency. Distinguish the two equations with subscripts "s" and "$\chi$" respectively, and divide to get the reaction probability for the study neutron field:

$$[\sigma_{calc} \cdot \Phi]_s = \frac{D_s}{D_\chi} \cdot \frac{\mu_s}{\mu_\chi} \cdot \frac{(NG)_\chi}{(NG)_s} \cdot [\sigma_{calc} \cdot \Phi]_\chi \tag{5}$$

$$= K \, \frac{D_s \, \mu_s}{(\epsilon NG)_s} \tag{5a}$$

$$= K_1 \, \frac{\mu_s}{\mu_\chi} \left(\frac{D}{NG}\right)_s (\sigma_\chi)_{calc} \tag{5b}$$

where K is given in Eq.4 and,

$$K_1 = \Phi_\chi \cdot \left(\frac{D}{NG}\right)_\chi^{-1}$$

Equation (5a) is used when the absolute detection efficiency, $\epsilon$, is employed to determine the reaction probability. In this case, K can be taken as a bias factor associated with the overall accuracy of the absolute measurement method including the spectrum averaged cross section. This procedure is sometimes referred to as measurement validation. Equation (5b) with a modified calibration factor, $K_1$, that excludes the detection efficiency is used when the detection efficiency is unknown or by-passed. When this procedure is used to obtain a neutron fluence, it is referred to as neutron fluence transfer.

## 4. Fission Chamber Measurements

Average neutron fluence rate, the natural outcome of fission chamber measurements, is obtained by dividing the measured average reaction rate by the spectrum-averaged cross section. Spectral indexes are obtained directly with Eq.3. Because they record reaction rate directly, fission chamber measurements, when instrument access is possible, generally provide results that are more accurate than those obtained with activation detectors.

When NIST fission chambers and fissionable deposits are used, a fission spectrum calibration is automatically available without explicit exposure in a fission spectrum field at NIST. To see this, combine Eq.(1b) (using $(\sigma_\chi)_{calc}$ as noted above) and Eq.2a (with G = 1/T). Use subscripts "s" and "$\chi$" to distinguish the study neutron field and the fission spectrum exposures. Divide to get,

$$[\sigma <\phi>]_s = \frac{D_s}{D_\chi} \cdot \left(\frac{\mu}{\epsilon N}\right)_s \cdot \left(\frac{\epsilon N}{\mu}\right)_\chi \cdot (\sigma_\chi)_{calc} \cdot <\phi_\chi> \quad .$$

An effective fission spectrum calibration is established by setting $[D_\chi / <\phi_\chi>] = (\sigma_\chi)_{meas} / [\mu/(\epsilon\ N)]_\chi$ to get for the average reaction rate,

$$[\sigma \cdot <\phi>]_s = \frac{\mu_s \bullet D_s}{\epsilon \bullet N} \cdot \frac{(\sigma_\chi)_{calc}}{(\sigma_\chi)_{meas}} \quad , \tag{6}$$

where N is the number of detector atoms specified by NIST, $\epsilon$ the intrinsic ionization chamber efficiency (very close to unity), and $(\sigma_\chi)_{meas}$ is the NIST measured cross section given in Ref. 1 (Table X-16, page 66) or Sect. D.2 of "NIST Cavity Fission Source / Facility Characteristics (1997)

## 5. Other Parameters

a. Fission-equivalent neutron fluence

$$\phi_{\chi\text{-}eq} = \frac{R_s}{R_\chi}\,\phi_\chi = \frac{[\sigma_{calc}\,\Phi]_s}{(\sigma_\chi)_{calc}} \tag{7}$$

where $R_s$ and $R_\chi$ are reaction probability measurements in the study neutron field and a fission spectrum neutron field carried out with the same detector system. This convenient measured quantity is independent of a spectrum calculation which is often subject to change or not immediately available to the experimenter. As indicated, the neutron fluence in the study neutron field is obtained by multiplying the fission-equivalent neutron fluence by the ratio of the calculated fission spectrum cross section, $(\sigma_\chi)_{calc}$, to the cross section for the study neutron field, $(\sigma_s)_{calc}$, from a transport calculation. All of this may be done equivalently in terms of the neutron fluence rate.

b. Truncated neutron fluences and cross sections

The average reaction rate may be expressed in terms of a spectrum fraction and a truncated cross section in order to facilitate uncertainty analysis by displaying the similarity of detector responses in the neutron field under study and in the fission spectrum employed for calibration. (See Ref.4, Section C.1 and D.1.1, or Ref.1, Section 5a)

Eq.5b for the reaction probability obtained with activation detectors, for example, may be written,

$$[\Phi_s \cdot \psi_s(>E_0)] = K_1\,\frac{\mu_s}{\mu_\chi}\left(\frac{D}{NG}\right)_s \left(\frac{\sigma_\chi(>E_p)}{\sigma_s(>E_p)}\,\psi_\chi(>E_p)\,\frac{\psi_s(>E_0)}{\psi_s(>E_p)}\right)_{calc} \tag{8}$$

where commonly $E_0 = 1$ MeV for reactor dosimetry, and $E_p = E_{95}$, the energy above which 95% of the detector response occurs. As an example, quantities in the bracket on the right are given in Table 1 for $E_0$=1 MeV and $E_{95}$ for detectors used in spectrum characterization measurements at the MDRF. Uncertainty propagation formulas are in Ref.4, Section C.1.4 and Ref.1, Section 5a.

## 6. Sample Inventory of Uncertainty Elements for Neutron Fluence Measurement With Activation Detectors

For a neutron fluence measurement with activation detectors, fission spectrum calibration, and calculated cross sections expressed in terms of spectrum fractions and truncated cross sections (Eq.8), the uncertainty elements to be estimated are as follows:

a. Experimental quantities

>Differences in $\mu$ between irradiations in the fission spectrum and in the study neutron field
--changes in counting procedures and corrections (e.g. shelf factors, pulse loss, background and competing reactions, gamma-absorption)
--corrections for neutron field perturbations by detector foils and encapsulation
>Ratio of detector responses, $D_s/D_\chi$, and the number of detector atoms
>Ratio of activation decay rate factors for the corresponding irradiation time histories
>Certified fission neutron fluence that appears in $K_1$

b. Ratios of spectrum fractions and truncated cross sections in Eq.8
[threshold detectors only, and uncorrelated, multigroup uncertainties in neutron spectra and energy dependent cross sections]

>Uncertainty propagation for ratios of spectrum fractions and truncated cross sections for dosimetry measurements in an operating power reactor are discussed in Ref.3. Uncertainty propagation formulas are given in Appendix B of that document.

>Formulation of uncertainty propagation for truncated cross section is given in section 5.a.3 of Ref.1. An *ad hoc* error may be estimated on the basis of the departure from unity of truncated cross section ratios, e.g., column 5 of Table 1.

>Uncertainties in calculated fission spectrum cross sections are given in Ref.1 (Table X-17(B5), p.67). They represent propagation of the uncorrelated, multigroup fission spectrum uncertainties given in Table X-5, p.29 in Ref.1.

TABLE 1. Spectrum Fractions, Cross Sections,and Ratios
For Spectrum Characterization Measurements in MDRF

| Detector | U235 Fission Spectrum | | | $\frac{\sigma_\chi(>E_p)}{\sigma_s(>E_p)}$ | | $\frac{\psi_s(>E_0=1\ \mathrm{MeV})}{\psi_s(>E_p)}$ | |
|---|---|---|---|---|---|---|---|
| | $E_p(p=95)$ (MeV) | $\sigma_\chi(>E_p)$ (barns) | $\psi_\chi(>E_p)$ | MDRF | MDRF w/BIO | MDRF | MDRF w/BIO |
| $^{235}$U fiss: | 0.20 | 1.221 | 0.961 | 0.1428 | 0.677 | 0.232 | 0.327 |
| Np fiss: | 0.69 | 1.585 | 0.807 | 1.169 | 1.123 | 0.593 | 0.631 |
| $^{238}$U fiss: | 1.5 | 0.533 | 0.544 | 1.037 | 1.037 | 1.375 | 1.376 |
| $^{58}$Ni: | 2.1 | 0.265 | 0.376 | 1.135 | 1.132 | 2.064 | 2.066 |
| $^{54}$Fe: | 2.3 | 0.233 | 0.330 | 1.078 | 1.075 | 2.514 | 2.517 |
| $^{46}$Ti: | 3.8 | 0.0798 | 0.1330 | 0.875 | 0.876 | 7.25 | 7.21 |
| $^{127}$Al$\alpha$: | 6.5 | 0.0358 | 0.0191 | 0.932 | 0.932 | 40.3 | 40.1 |

NOTES
$\sigma_s$ and $\psi_s$ are for MDRF from NIST 2-D DORT calculations MDR20 and MDR20b.
Fission spectrum values are for the ENDF/B-V $^{235}$U fission spectrum, the source spectrum for MDRF calculations.

Ref. E. 1.1-2

October 1, 1996

fac/flucal

MEMORANDUM FOR Jim Adams

From: Dale McGarry and Jim Grundl

Subject: Status of Neutron Fluence Calibrations for NIST Standard Neutron Fields

Reference: Formulations For Neutron Field Characterization Measurements With Integral Detectors (31July96)
Test Report: "Neutron Fluence Calibration at the $^{235}U$ Cavity Fission Source"

This brief review is primarily aimed at the application of NIST standard neutron fields for calibration and/or validation of activation measurement methods employed in power reactor dosimetry. In this application, it is recognized that the end result of reactor dosimetry is a neutron fluence, generally for E>1MeV. A short discussion is included of a proposed application of MDRF to a measurement problem with fission dosimeters that has come to the fore recently.

1. Activation Equation

The neutron fluence in NIST Standard Neutron Fields is currently determined on the basis of neutron fluence transfer from CNIF using Ni58(n,p) activation monitors. The activation equation for this purpose in terms of reaction probability is,

$$\sigma \Phi = [\mu D / NG] [1/\epsilon] \tag{1}$$

where,

$D$ = gamma counter response (counts/sec with appropriate corrections)
$\mu$ = residual detector response factor (i.e. corrections not in D)
$N$ = number of detector atoms
$G$ = activation decay rate factor
$\epsilon$ = gamma detection efficiency
$\sigma$ = spectrum averaged cross section
$\Phi$ = neutron fluence
$[\sigma \Phi]$ = reaction probability

The activation equation in terms of average reaction rate $[\sigma \phi]$ is just the above equation divided by T, the length of irradiation.

2. Cf Neutron Irradiation Facility, CNIF

The neutron fluence at CNIF is based on the absolute neutron source strength of Cf252 fission neutron sources, a distance measurement, and calculated neutron scattering corrections.

3. Cavity Fission Source (CFS) and the Materials Dosimetry Reference Facility (MDRF)

The following quantities are involved in neutron fluence transfer from CNIF to CFS and from CFS to MDRF:

(a) the counter response of the Ni58 fluence monitor irradiated to a known neutron fluence at CNIF
(b) the ratio of calculated cross sections for Ni58(n,p): $\sigma$(Ni,$\chi$Cf)/$\sigma$(Ni,$\chi$U5) and $\sigma$(Ni,$\chi$U5)/$\sigma$(Ni,mdrf)

Cross sections for these ratios must be calculated since source strength and source geometry cannot be accurately established for CFS and MDRF.

The working expression for determining a certified neutron fluence in the case of CFS is,

$$\phi_{cfs} = [\mu\ D\ /\ NG]_{cfs} \times [\phi\ /\ (\mu\ D\ /\ NG)]_{cnif} \times [\sigma(\mathrm{Ni,\ CNIF})\ /\ \sigma(\mathrm{Ni,\ CFS})] \qquad (2)$$

It is obtained by dividing Eq.1 for CFS by Eq.1 for CNIF and re-arranging. The quantity in the middle bracket is measured periodically for relevant counting geometries. A current value is for shelf geometry "blue-hi-1/2" is 6.50E5 with an uncertainty close to 1%.

The calculated cross sections for neutron fluence transfer are listed in Table 1. They use data from NIST and ENDF/B-V, in particular, the dosimetry cross section file in ENDF/B-V. The latter was set up specifically for reactor dosimetry applications and has a long history of use in reactor physics and the power reactor industry. Other cross sections that may have to be evaluated for future use, notably ENDF/B-VI data, are given in Table 2.

4. Validating Industry Dosimetry

NIST irradiates industry dosimeters in CFS or MDRF to a certified neutron fluence which may be compared directly with the fluence obtained by the customer with data from his counting laboratory. Alternatively, an average reaction rate or reaction probability can be specified if these dosimetry related quantities are needed for comparisons with transport calculations.

The latter, validated for neutron fluence determination, is obtained as the product of the certified neutron fluence rate (or fluence) and a consistent calculated cross section for the standard neutron field. Consistent means calculated with the same U235 fission spectrum shape and energy dependent detector cross sections that are used to calculate cross sections for the neutron field for which dosimetry validation is sought. NIST test reports routinely include calculated cross sections for each detector type irradiated based on the ENDF/B-V dosimetry file and the spectrum option given in Table 1. Other options for the calculated cross sections can be furnished. It is to be noted that using a measured cross section for validating dosimetry measurement methods would reduce the standard neutron field referencing procedure to an isolated and ambiguous check of counting lab detection efficiency.

5. Fission Activation Dosimeters

The difficulty of determining individual fission product activities for Np237 and U238 fission activation dosimeters has come into prominence recently. An important example is counting the low-energy gamma from the long-lived Cs137 fission product in the presence of time dependent interference from all of the other fission product activities.

Activity standards that are themselves fission dosimeters with fission product activities in the range of working fission dosimeters could validate or even calibrate Cs137 gamma counting procedures. Such fission product activity standards (FPAS) can be prepared in MDRF with fission product activity that is close to that obtained in PWR cavity dosimetry measurements.

The key to establishing fissions per nucleus in the standard is the absolute fission chamber measurements performed during the MDRF field characterization project. Fissionable isotopes included were Np237, U238, and U235. Most important, some of the fission chamber measurements were specifically monitored with the Ni58(n,p) reaction in order to obtain a complete set of spectral indexes for MDRF. Thus, a fission calibration factor for the Ni58 reaction can be derived and used with Ni monitors of FPAS irradiations in MDRF.

The application of the fission product activity standard (FPAS) can be seen from Eq.1 set out in terms of average reaction rate and solved for $\epsilon$, the detection efficiency:

$$\epsilon = [\mu \, \mathbf{D} / \mathbf{NGT}] / [\sigma \phi]$$

The detection efficiency is established on the basis of the following

> **[$\sigma \phi$]**, the average reaction rate certified for the FPAS (fiss./s,nucl.)
> **D**, the net counts/s in the Cs137 gamma peak determined with routine counting lab procedures
> **NGT** from the half-life of Cs137, and the fissionable isotope mass of the FPAS
> $\mu$ consisting of the Cs fission yield and small corrections for neutron scattering

Extraneous quantities from the literature are the half-life of Cs137 (very well known) and Cs137 fission yields for each isotope (less well known but estimated to be 3.5%). The disagreement of the detection efficiency based on the FPAS with that obtained with a conventional single-line Cs137 gamma standard will indicate how well the Cs137 gamma line has been extracted from the total fission product activity.

The FPAS is also a neutron fluence standard established as described in #3 above and to be applied as outlined in #4. As a neutron fluence standard, it provides a comprehensive validation of neutron dosimetry measurement methods; as a fission product activity standard, it provides a diagnostic reference for examining fission product gamma counting procedures.

This proposal for producing fission product activity standards will be incorporated into a NUREG that will call attention to the pitfalls of Cs137 fission product counting directly with fission dosimeters without chemical separation.

cc: D. Gilliam

Table 1. Ni58(n,p) Cross Sections Currently Used To Establish Neutron Fluence For NIST Standard Neutron Fields

| Neutron Field | Spectrum | Cross Section (barns) | | $\psi$(E>1MeV) |
|---|---|---|---|---|
| | | $\sigma$(E>0.4ev) | (1)$\sigma$(>$E_{95}$) | |
| CNIF | NBS Eval. $\chi$Cf | 0.1138 | 0.265 | 0.703 |
| CFS | ENDF/B-V $\chi$U5 | 0.1050 | 0.265 | 0.699 |
| MDRF | Transport Calc: mdr20 | 0.0275 | 0.234 | 0.231 |
| MDRFw/B10 | Transport Calc: mdr20b | 0.0389 | 0.234 | 0.326 |

(1) Cross section truncated at $E_{95}$, the energy above which 95% of the detector response occurs. Such cross sections facilitate uncertainty analysis by displaying explicitly the similarity of detector response in neutron fields of interest. The values for NIST standard neutron fields are seen to be within ±10% of the average.

Notes:
The Ni58(n,p) cross section vs energy is from the ENDF/B-V Dosimetry File.
The cross section $\sigma$(E>1MeV) = $\sigma$(E>0.4ev) / $\psi$(E>1MeV) (col.3 divided by col.5)
The MDRF transport calculations use U235 fission spectrum from ENDF/B-V.

Table 2. Ni58(n,p) Cross Sections From Other Evaluations

| Neutron Field | Fission Spectrum | Cross Section vs. Energy | Cross Section (barns) $\sigma$(E>0.4ev) | Ratio to value in Table 1 |
|---|---|---|---|---|
| CNIF $\chi$cf | ENDF/B-VI | ENDF/B-V | 0.1132 | 0.995 |
| CNIF $\chi$cf | ENDF/B-VI | ENDF/B-VI | 0.1153 | 1.013 |
| CFS $\chi$U5 | ENDF/B-V | ENDF/B-VI | 0.1067 | 1.016 |
| CFS $\chi$U5 | ENDF/B-VI | ENDF/B-VI | 0.1057 | 1.007 |
| CFS $\chi$U5 | NBS Eval. | ENDF/B-V | 0.1009 | 0.961 |

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E.3.1 Diskettes, WP5.1

NISTIR DOCUMENTS FOR CAVITY FISSION SOURCE

[Directory NISTIR.CFS On diskette labelled NISTIR.CFS]

CFS--Operations Manual: rcfsoper.jno; *.ref; *.hid

CFS--Facility Characteristics: rcfschrab; rcfschrc; rcfschrd; rcfschre

CONTRACT DOCUMENTATION

[from docsnf\cfsdoc, prefix "cfs" indicates primary files for CFS]

DOCNSF Directory (diskette 1)

>cfsdoc master file for CFS documenation
>cfsoper master file for CFS Operations Manual
>cfschar master file for CFS Facility Characteristics
>cfschrab working file for sections A and B of CFS--Fac. Char.
>cfschrc working file for section C of CFS--Fac. Char.
>cfschrd working file for section D of CFS--Fac. Char.
>cfschre working file for section E, references

General

**>snfdoc Master summary of SNF documentation**
>snffiles master index of SNF WP5.1 files and manilla folders
>INTERTRN <Dir> intermediate files for document transfer
>sdoctrn log of transfer of NSF documentation
>stndfld CE document, Ref.1.1-13 in Section E of CFS--Fac. Char. Doc.
>formulas Formulations for Neutron Field Char. With Integral Detectors
Ref.1.1-1 in Section E of CFS--Fac. Char. Doc.
>refpub Reference lists and locations for SNF documentation
>snftable table: Characteristics of NIST Standard and Reference Neutron Fields

FAC Directory (diskette 2)

>cfsdoc; >cfsoper; >cfschar (s.a. DOCSNF)
>cfschrab; >cfschrc; >cfschrd; >cfschre (s.a. DOCSNF)
>cfstrpts test reports for fluence standards
>cfsforms.tr test report forms and related
>cfscalc.n95 cavity return and capsule scattering calculations
>cfssck.cal fluence derivation from CEN transfer project (obs.)
>cfsmisc photofission

General

**>flucal** JG,EDM memo to Adams re. status of neutron fluence calibration for NIST Standard Neutron Fields / fluence calibration paths for all fields /
>thcolop thermal column operations: notes, upgrade, old manual text
>irrlogs irradiation logs for CFS, Cf252, Thermal
>miscfab fission chamber and PUDS fabrication

DOC DIRECTORY [general SNF project documentation, partial list of files]

>formulas, >refpub s.a. as in DOCSNF
>spadg input/output glossary for SPAD code
>traudit audit of test reports (1989)
>thkthn thick vs thin detector response
>puds description of PUD detectors

DATA ANALYSIS CODES

>DETAN: Converts an input neutron spectrum to detector response parameters, response functions, or alternative spectrum group structure.
(see Section D.1.3 in CFS-Fac. Char. Doc.)
[Ep5.1: C:\DETAN]

>FLUDER: Neutron fluence derivation from fluence monitors
[WP5.1 C:\CFSCODES\FLUDER]

>SCATCOR: Neutron scattering corrections
[WP5.1 C:\CFSCODES\SCATCOR]

>QPRO: Directory QPRO on C:\ disk
--Spread sheet for FLUDER (Sect. B.2 in CFS--Operations Manual
--Data for spectrum plots of fission spectra and MDRF

E.3.2 Manilla Folders

>CFS: Operations Manual
>CFS: Facility Characteristics Manual
>CFS: General Information
---Documentation List for CFS
---Accumulated "Notes"
---Fluence Determination
---Axial Gradient and Related
---Radial Gradient
---Irradiation Time History
>CFS: Calculations
---1995 Monte-Carlo
---1994 ANISN
---Eisenhauer memos
>CFS: Miscellaneous
---Miscellaneous
---Low Energy Detector Response
---Obsolete Information
>CFS: Construction and Hardware Photos
---construction
---some photo originals
---hardware photo album (captions)
>CFS: Literature

>CE(97): Compendium of Scattering Calculations (Eisenhauer memos)

>CE(97): ENDF/BVI XSCTNS
--Ref.E.1.1-13: Documentation of Assumptions and Models In Neutron Transport Codes Used to Calculate Neutron Spectra in NIST Standard and Reference Fields 15Feb98
--Misc DETAN printouts and analysis sheets

>Eisenhauer Documentation >95
---"DETAN96: Documentation Of Interactive Code For WP5.1" June96 [NISTIR 5622]
---"Directory and Explanation of CRAY Files Generated by the DETAN Computer Code"